National Aeronautics and Space Administration

SPACE LAUNCH SYSTEM

Fundamentals of Launch Vehicle Ablative Thermal Protection System (TPS) Materials

TFAWS2017

Darrell Davis

CFD, Miniver, Design, and Thermal…

What is TPS?

Thermal Protection System

- A system designed to protect a spacecraft from exposure to thermal environments
  - Ascent/Re-entry
  - Natural Environments
  - Orbital Environments

Different classes of TPS

- Ablators
- Insulators
- Multi-Layer Insulation (MLI)
- Blankets

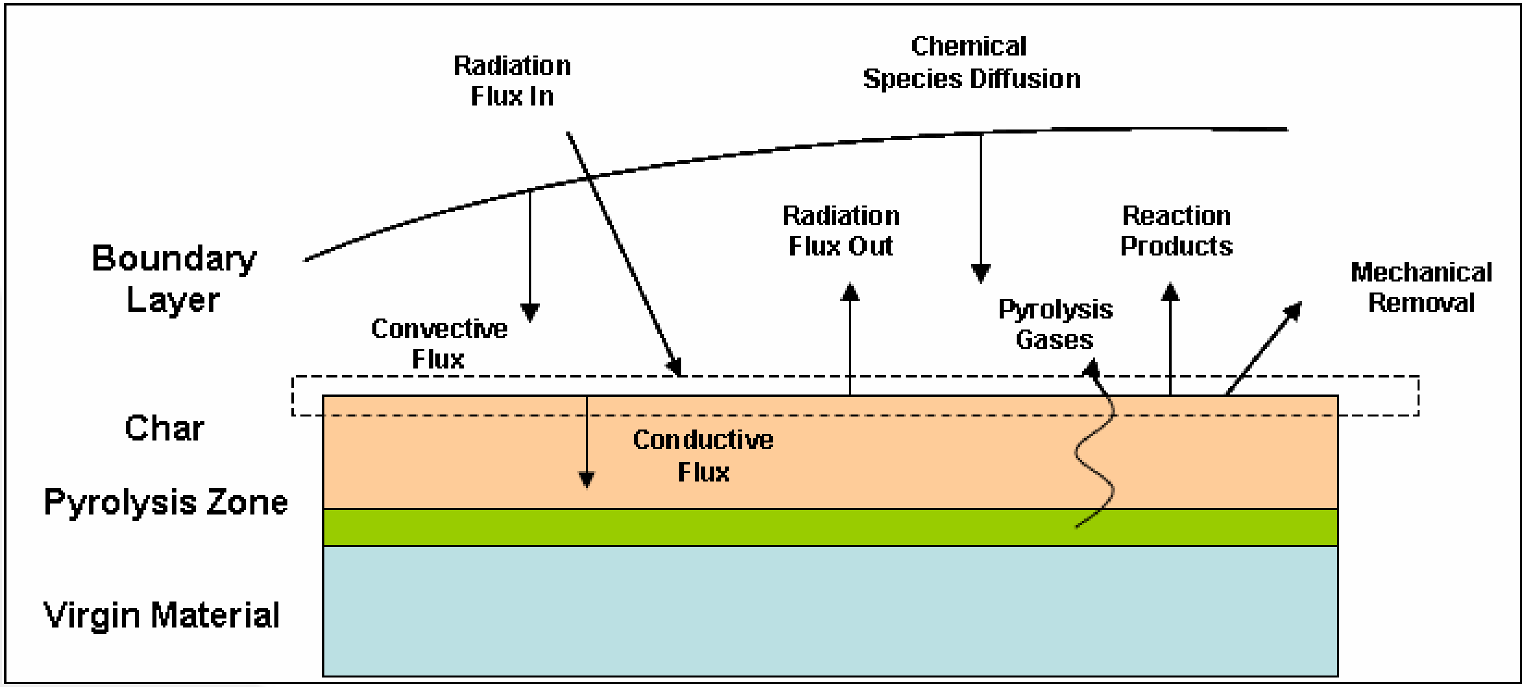
Which TPS To Use?

- Many factors determine which TPS to use
  - Weight
  - Processing
  - Purpose
  - Optical Properties
  - Exposure to Environments
  - Special Properties
  - RF Transmissivity
  - Durability during processing

- Collaboration with Materials & Processing to determine which material is best

Ablators

- Ablative materials are designed to provide thermal protection through loss of mass.
  - Mechanical removal & pyrolysis gases takes energy
  - Exposes relatively cooler material



Ablative Materials – MCC-1

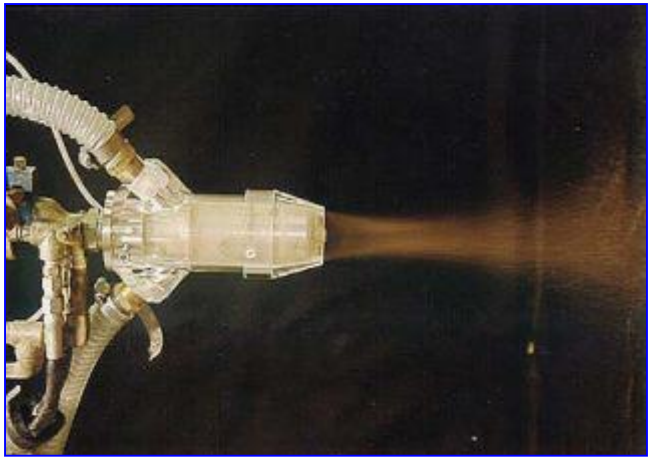
- First flight of Marshall Convergent Coating (MCC-1) was in 1996.
  - Prior to that, SRB used Marshall Sprayable Ablator (MSA)
  - MSA had low tensile strength
  - MSA had wasteful batch process
  - Surface imperfections required frequent repair
  - Lot of “pop-offs” that would damage orbiter tiles

- Developed CST technology to remove issues
  - Able to choose durable epoxy
  - No batch issues
  - Easily monitor flow rates

MSA pop-off

Ablative Materials – MCC-1

- Marshall Convergent Coating (MCC-1)
  - Two part epoxy adhesive filled with ground cork and glass ecospheres.
- Sprayable ablative TPS developed for Space Shuttle.
- Uses Convergent Spray Technology (CST) developed at MSFC.
- Primary SRB acreage TPS

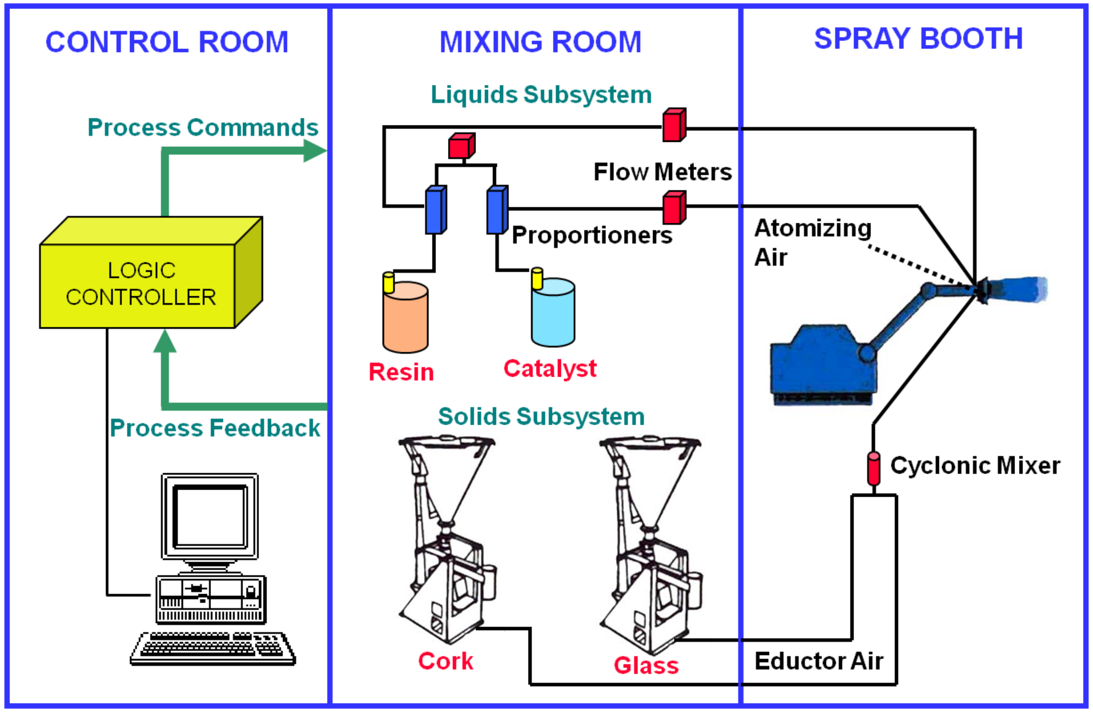


MCC-1 Spraying from Nozzle

MCC-1 Cross-Section and Surface

Ablative Materials – MCC-1

- Uses Convergent Spray Technology (CST) developed at MSFC.



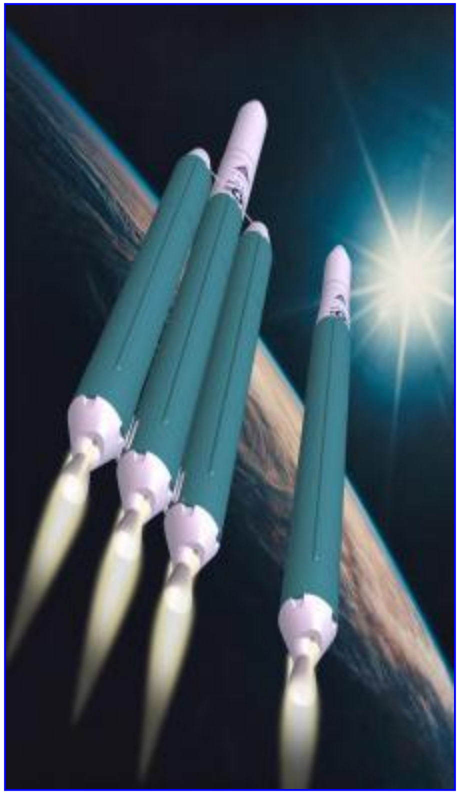
- Can use a wide range of liquid and solid ingredients to create other materials

Ablative Materials – MCC-1

- Technology Transfer
  - MCC-1 is used on other launch vehicles

SeaLaunch
Payload Fairings

Titan IV
Payload Fairings



Delta IV
Nosecones
Intertank

Ablative Materials – MCC-1

- Technology Transfer
  - Convergent Spray Technology is used in non-space applications
  - Epoxy filled with abrasive flint tested on road surfaces

    - Skid Resistant
    - Durable
    - EPA Compliant

Ablative Materials – MCC-1

- Technology Transfer
  - Acrylic filled with recycled rubber tested on two MSFC building roofs
    - Weathers well
    - EPA Compliant
    - Uses recycled automobile tires

Ablative Materials – MCC-1

- Technology Transfer
  - Convergent Spray Technology is used in non-space applications
  - Unknown proprietary liquids and solids

Ablative Materials – MCC-1

- Technology Transfer
  - Convergent Spray Technology is used in non-space applications
  - Unknown proprietary liquids and solids

Ablative Materials – MCC-1

•MCC-1 is the main acreage TPS for the Space Shuttle Solid Rocket Booster (SRB)

- Nosecap
- Frustum
- Forward Skirt
- Aft Skirt
- Systems Tunnel

Ablative Materials – MCC-1

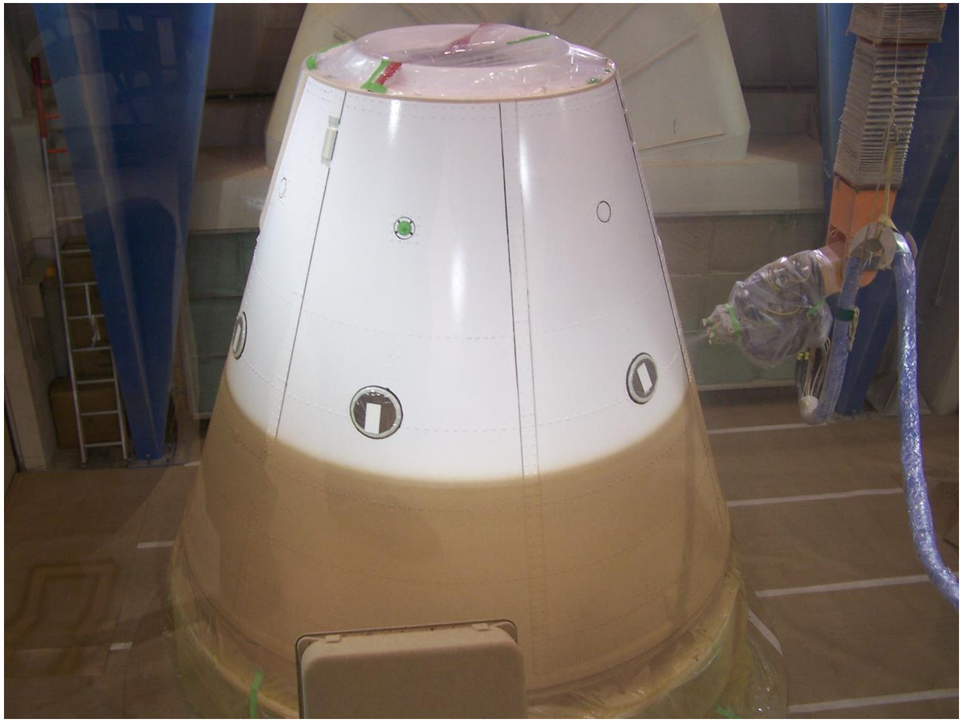
- MCC-1 application to Frustum
  - Spray parameters are controlled by computer software programs developed for each component.

  - Table rotation speed

  - Stand-off distance

  - Vertical movement of arm

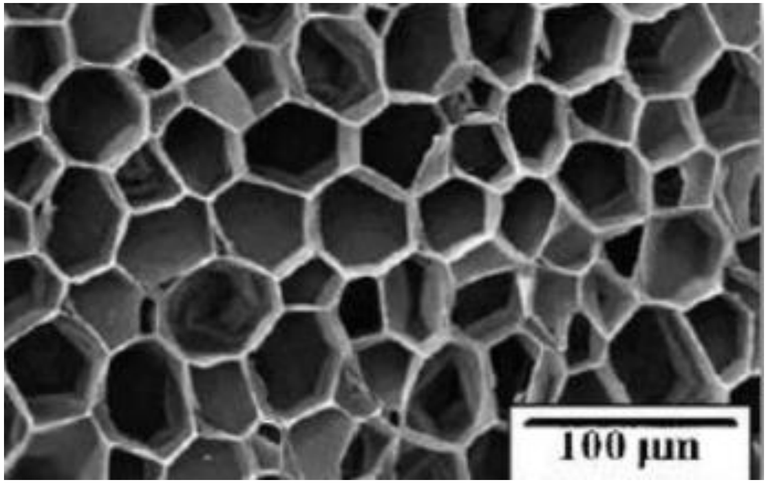
  - Constituent flow velocity



Ablative Materials - P50 Sheet Cork

- Insulative properties of cork have been known since ancient times
  - Cork is the bark of the Cork Oak tree
  - Grown mainly in Spain and Portugal

- Cork cells are small irregular pentagonal or hexagonal prisms.
  - 50% of cork is gas enclosed in cells
  - Low Conductivity
  - No convection between cell structure
  - Low radiation between cells.



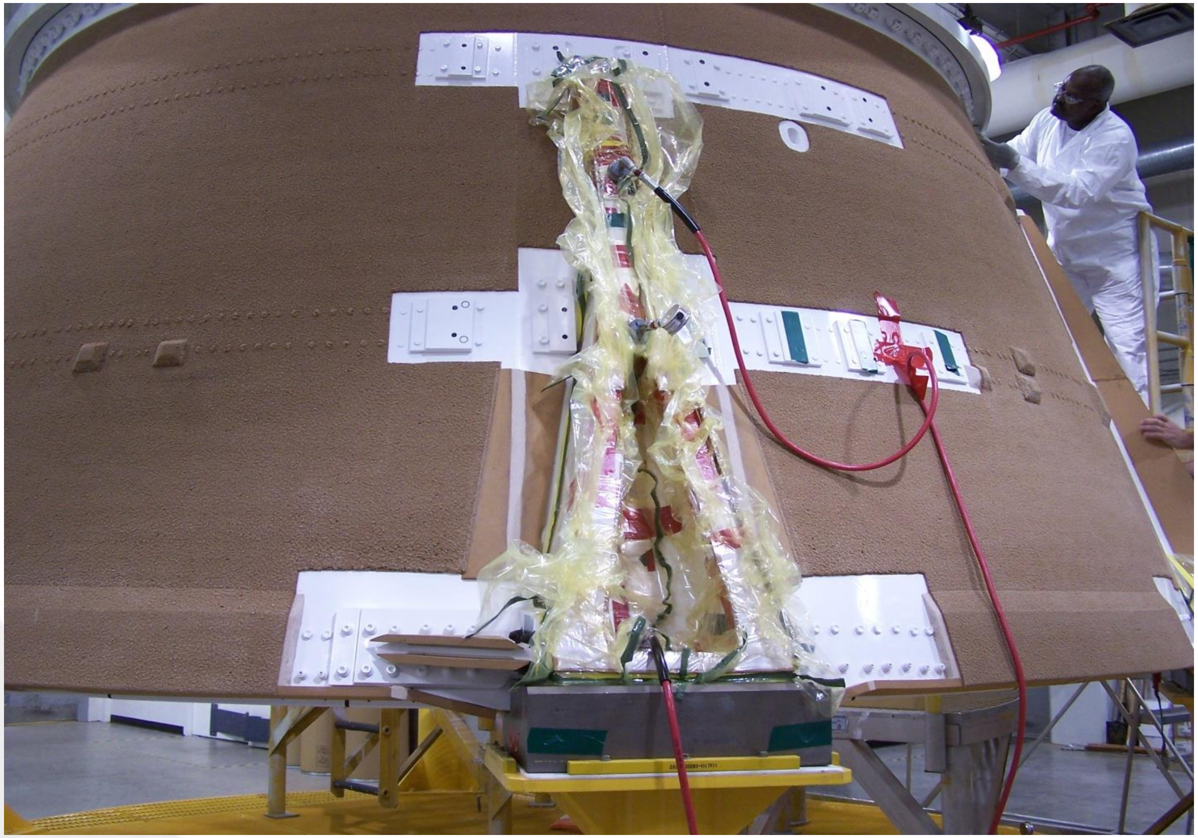
Ablative Materials - P50 Sheet Cork

- Cork has been used as a TPS from the beginning of space flight
  - P50 cork is a composite of ground cork and phenolic binders
  - Sheets of cork are purchased in relatively small sheets in specific thicknesses.
  - Sheet cork is used in areas that are hard to spray
  - It is easy to cut and machine

Ablative Materials - P50 Sheet Cork

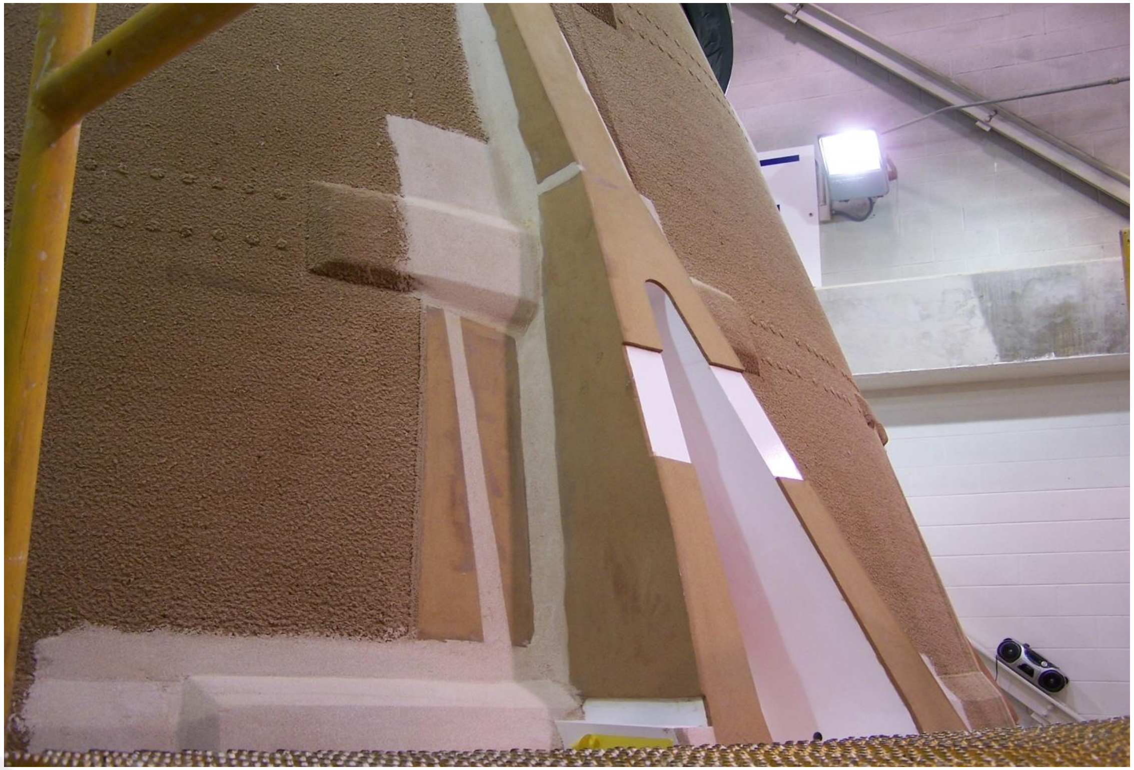
- . After the cork has been cut to shape, adhesive is applied to the both the cork and the substrate in defined thicknesses

- The hardware is then completely covered by a vacuum bag for a minimum of 8 hours. This helps ensure proper bonding.



Ablative Materials - P50 Sheet Cork

- Because of this labor intensive process and the small stock size, sheet cork is not recommended for large areas



Close Out Materials

- . Close out materials are hand applied and are used in areas where applying cork is not convenient, in final assembly operations, and for repairs.

- For shuttle operations there were two close out materials used:
  - BTA (Booster Trowellable Ablator)
  - Thermal Ablative Compound (RT-455)

- For SLS operations, only RT-455 is used.

RT-455 closeout on the Diagonal Strut

Close Out Materials

- . Booster Trowelable Ablator (BTA) is a mix of Epoxy, Glass Ecospheres and ground cork.
    - A vacuum mixer is required for processing.

- RT-455 is a mix of Polyamide Resin, Epoxy Resin, and ground cork
    - RT-455 can be mixed by hand or by a mechanical mixer

BTA closeout on BSM Housing

SF-EPDM

- Silica Filled Ethylene Propylene Diene Monomer
- High Temperature Rubber
- Used in High Heat / High Shear areas
  - For shuttle: Protuberances during re-entry
- Also used as a weatherseal on Factory Joints

SF-EPDM

Topcoats

- Why are the TPS materials white on the Booster?
  - Ablative TPS materials are covered with a moisture barrier topcoat.
  - Prevent fungus growth and moisture absorption from the ambient environment

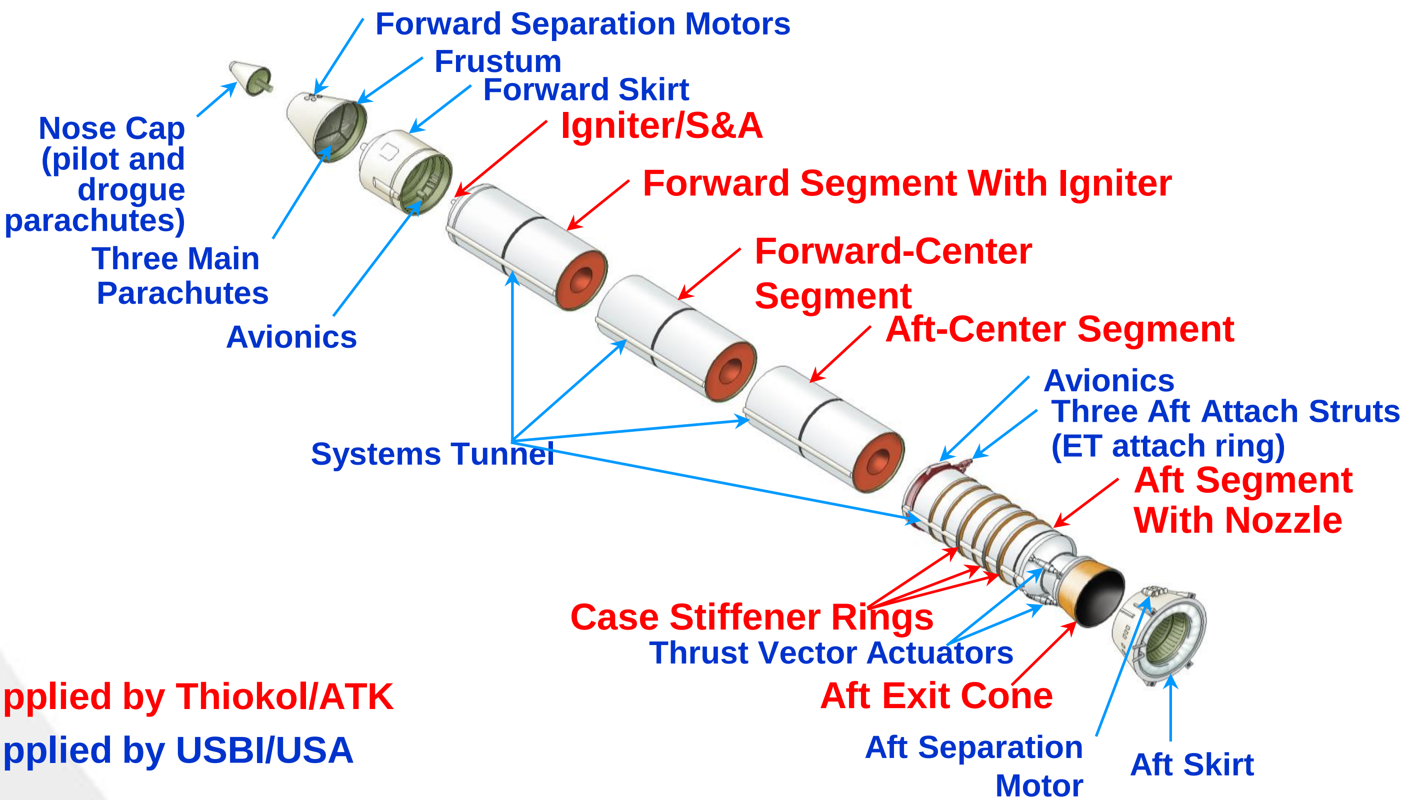
Topcoats

- Hypalon is an environmentally complain polyethylene paint
  - Made by Gaco Western,technically called GacoFlex.
  - Referred to as Hypalon because it contains Hypalon rubber
  - Percholoethylene free and lead free
  - Used on SLS hardware processed in Florida.

- Acrymax is an acrylic latex elastomer paint
  - Used on SLS hardware processed in Utah

Shuttle RSRB

Difference between SRB and RSRM



Supplied by Thiokol/ATK

Supplied by USBI/USA

SRB Nosecap

Acreage:
MCC-1

SRB Frustum

BSM Cover Plate
(not shown):
Cork

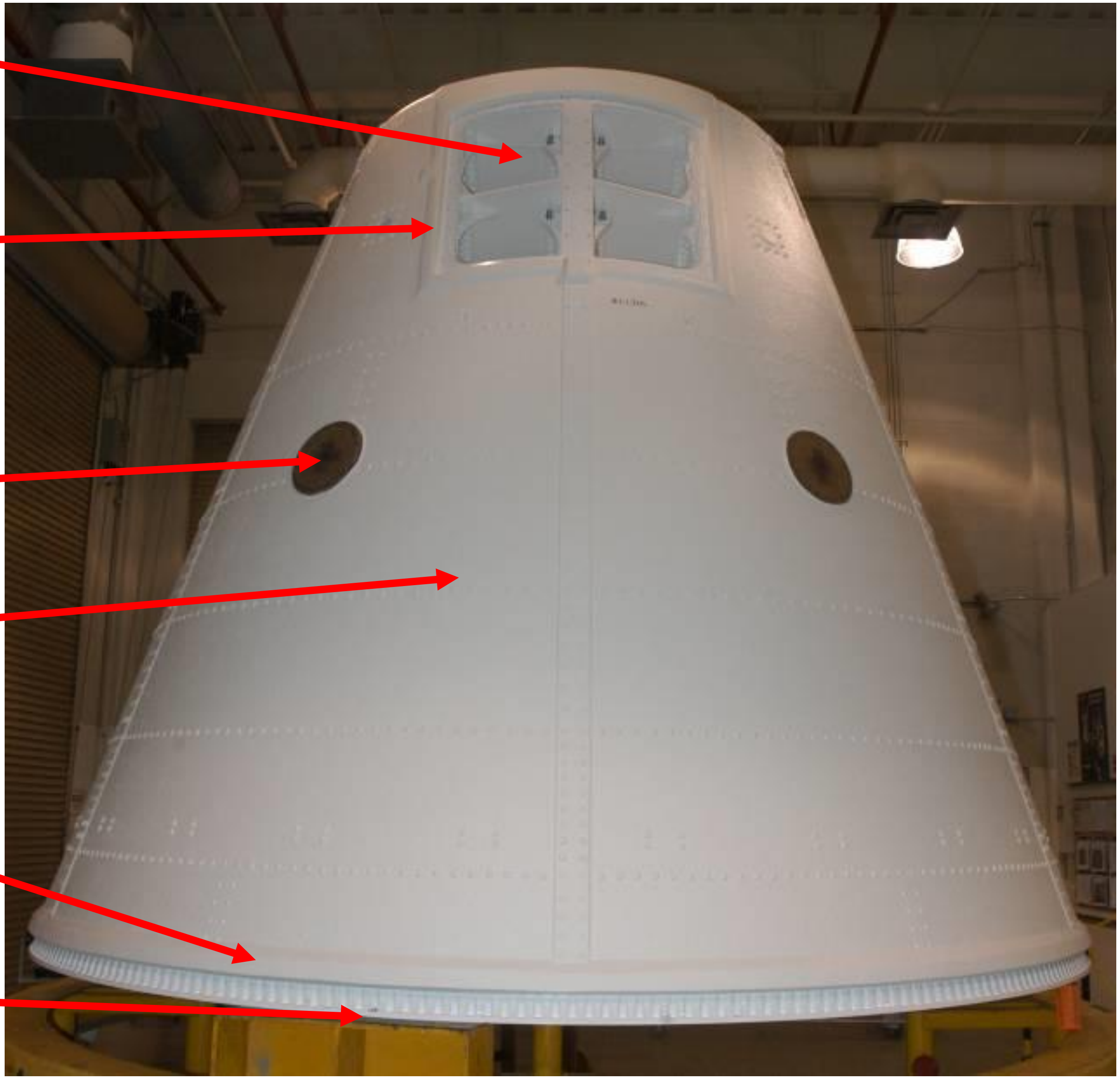
Closeout around
BSM Cover Plate:
BTA

Altitude Pressure Port:
Glass Phenolic

Acreage:
MCC-1

Trailing Edge:
MCC-1 over
BTA

Separation Ring:
Cork



SRB Forward Skirt

Acreage:
MCC-1

Access Door:
Bare

Forward Skirt Camera:
Cover: Machined Cork
Aft Face: BTA

Range Safety System Antenna:
SLA-220

SRB Forward Skirt

Forward Attach Fitting
(Thrust Post):
Cork

ET Observation Camera
BTA

Forward Skirt
Joint TPS:
Cork

Range Safety Crossover:
Cork
BTA and RT455

Boltcatcher
(Remains with ET):
Machined Cork

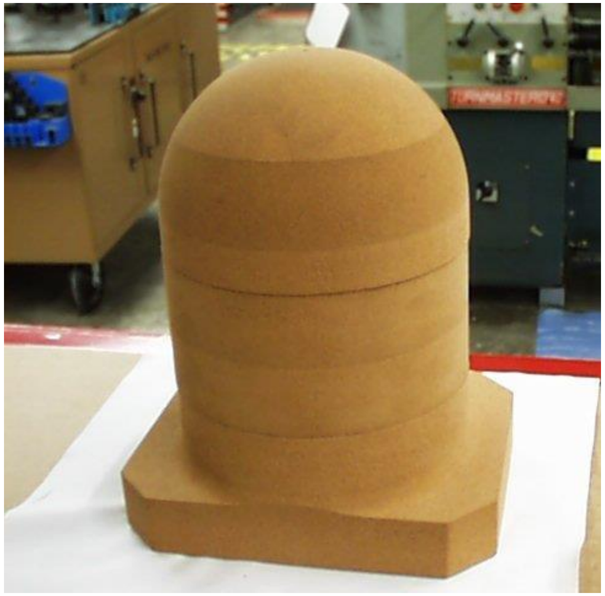
Boltcatcher

SLA-561

Silicone based
with cork filler

Used prior to
Columbia accident

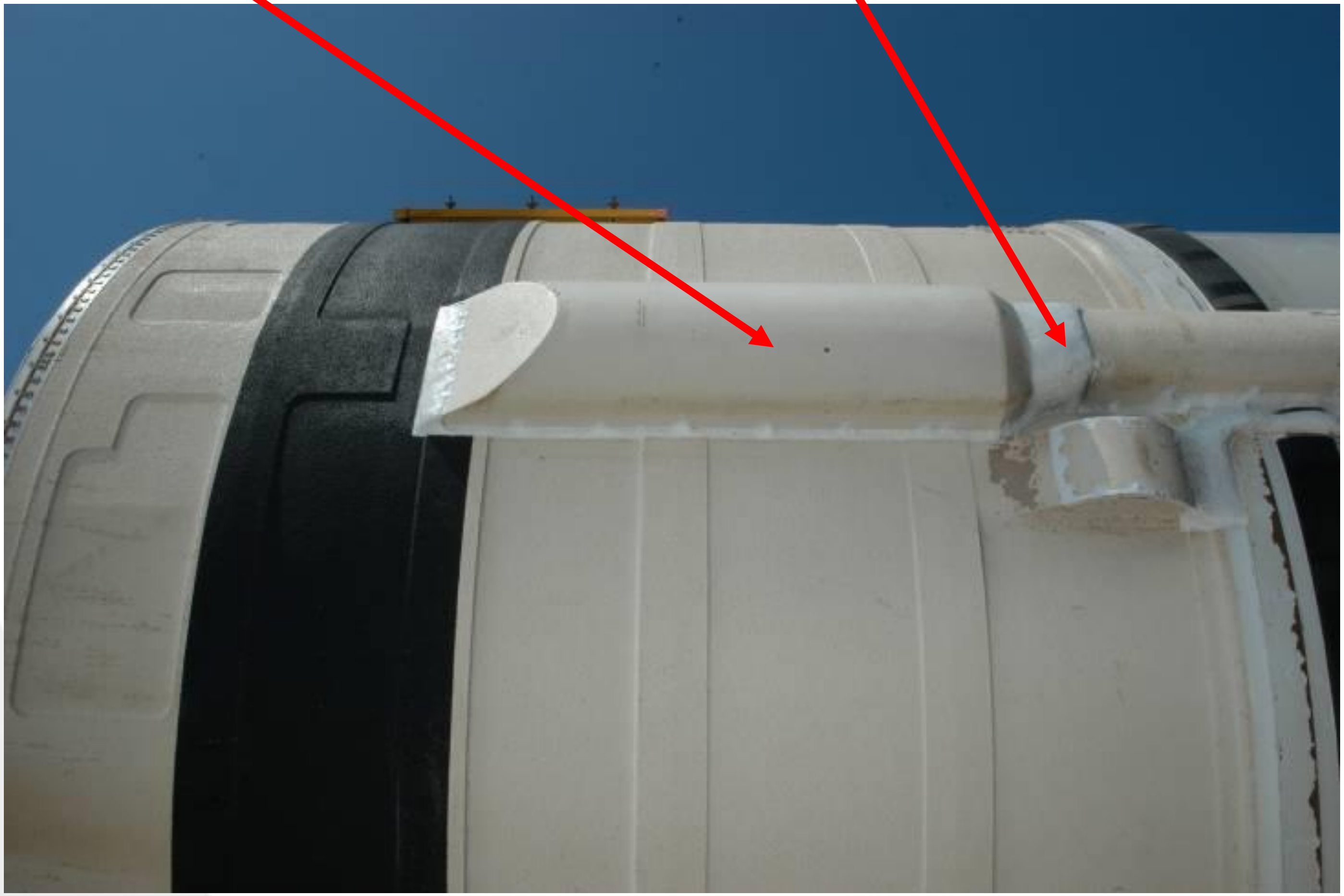
Machined cork used
after Columbia



SRB Forward Skirt

Forward Skirt Cover:
Cork

Closeout:
RT455



RSRM Motor Case

Factory Joint:
EPDM

GEI Run
Cork

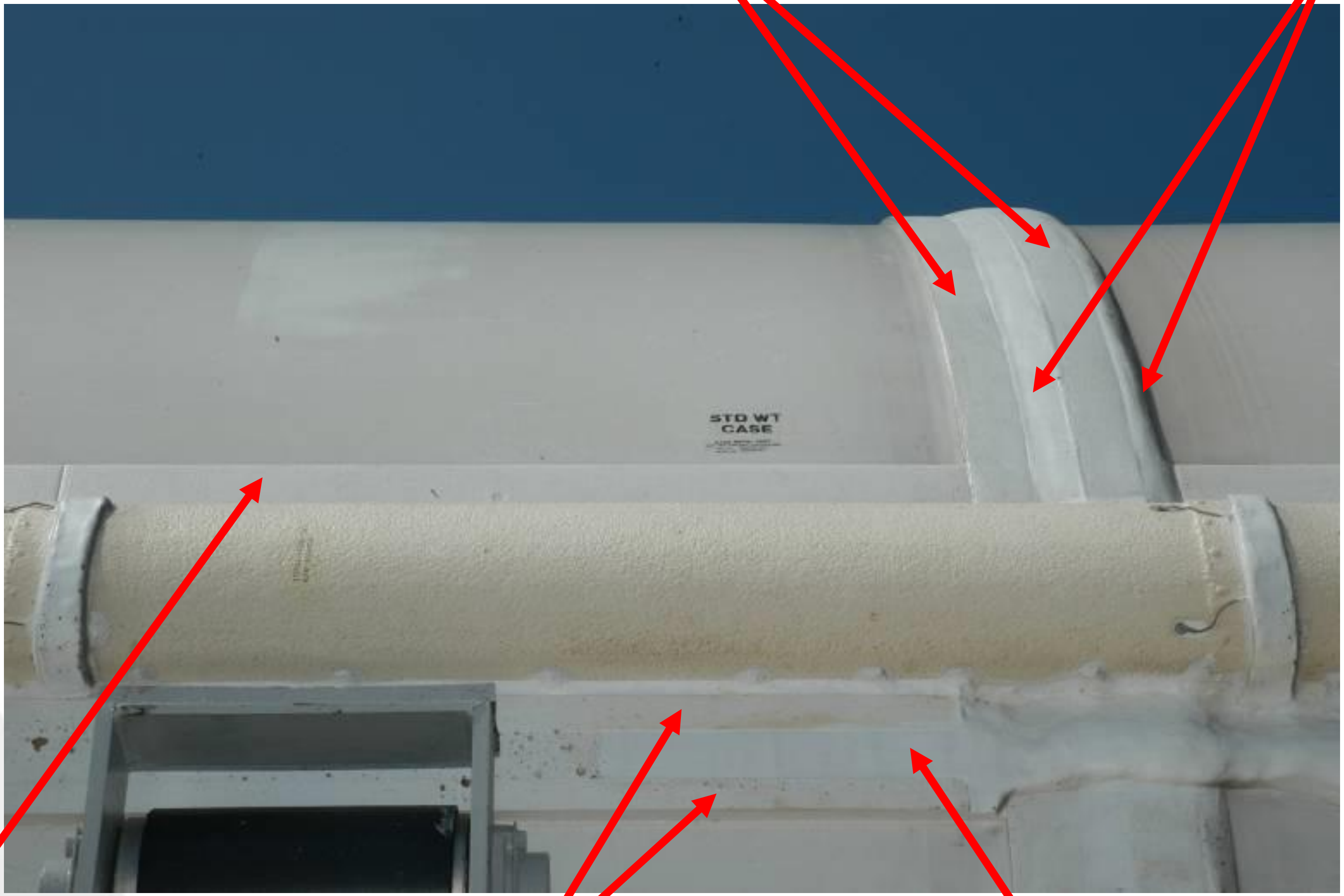
GEI Run
RT455

Systems Tunnel Cover:
MCC-1

RSRM Motor Case

Field Joint:
Cork

Field Joint:
RT455



System Tunnel Closeout:
Cork

Heater Cable Closeout:
Cork

Heater Cable Closeout:
RT455

Attach Ring and Aft Strut

ETAR Forward Web:
Froth Pak Foam
Over Cork

Porta-Pull Repair:
PDL

Strut Cover:
EPDM

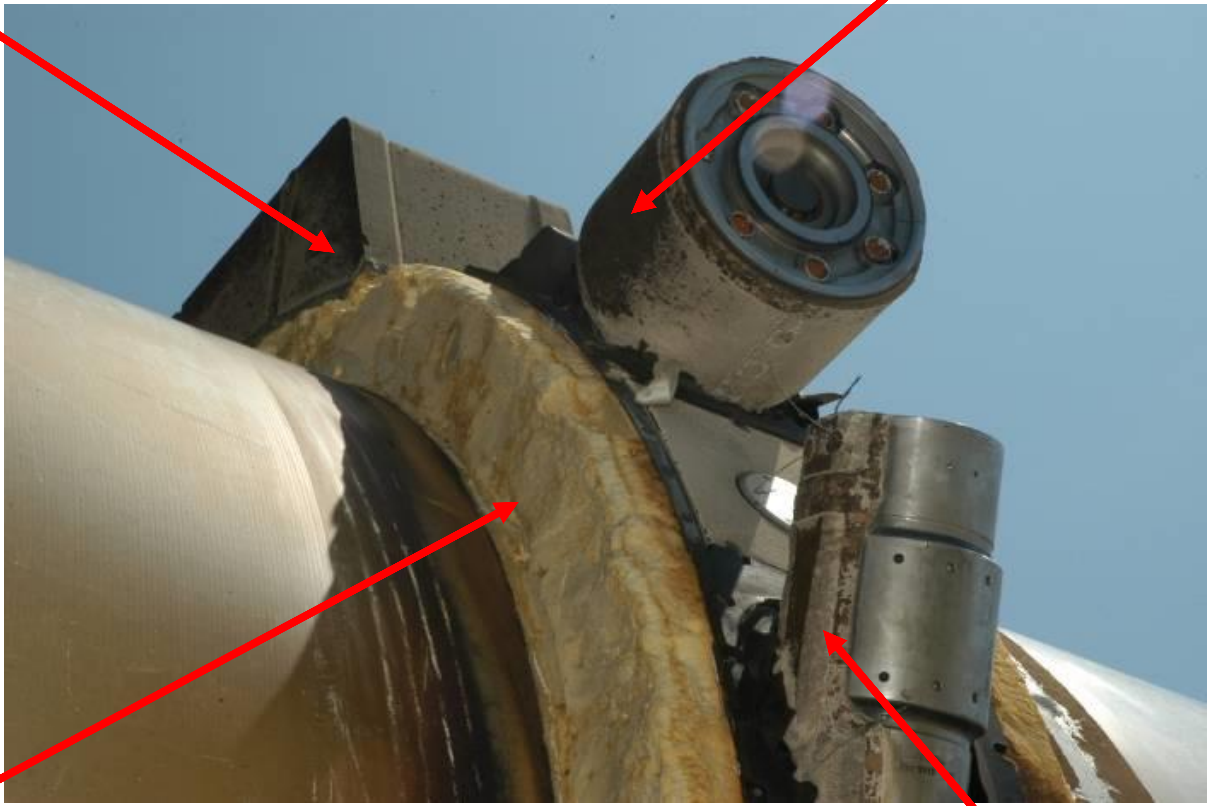
Outboard Cover:
Cork

Field Joint
Cork and RT-455

Attach Ring and Aft Strut

IEA Box Cover:
Cork

Upper Strut:
Cork
RT455 over fracture plane



ETAR Aft Web:
Froth Pak Foam
Cork

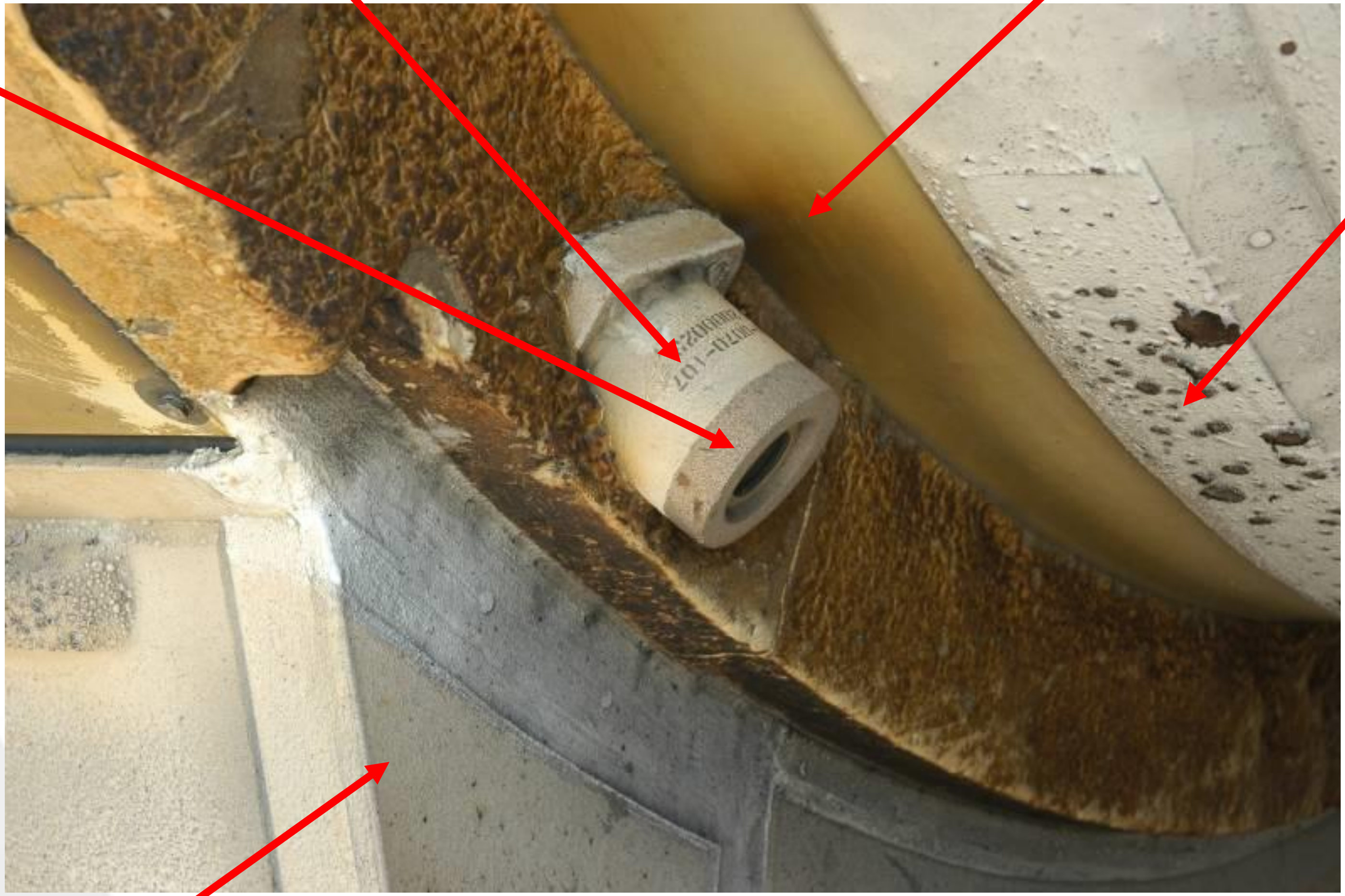
Diagonal Strut:
Cork
RT455 over fracture plane

Attach Ring Camera

Camera Body:
Machined Cork

Note: Off gassing of foam constituents

Close Out:
BTA



Field Joint

IEA Box:
Cork with RT455 Closeout

Aft ⟷ Forward

RSRM Motor Case – Aft Segment

TVC Access Doors
Bare Aluminum

Aft Crossover Housing
MCC-1

Aft Skirt
Joint TPS:
Cork

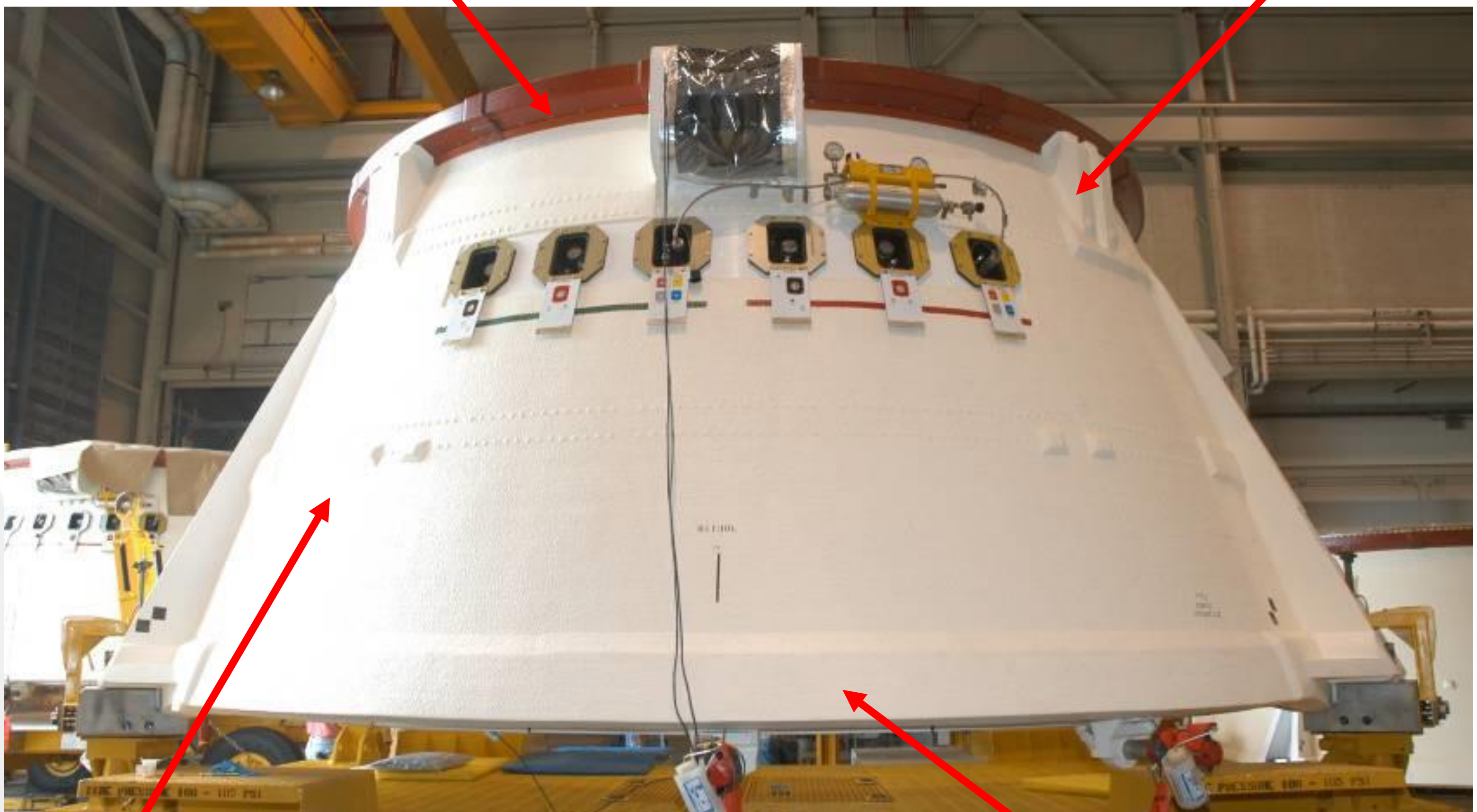
Stiffener Rings:
EPDM
Foam applied for water impact protection

Active Stiffener Stubs:
EPDM

SRB Aft Skirt

Kick Ring:
Phenolic Laminate

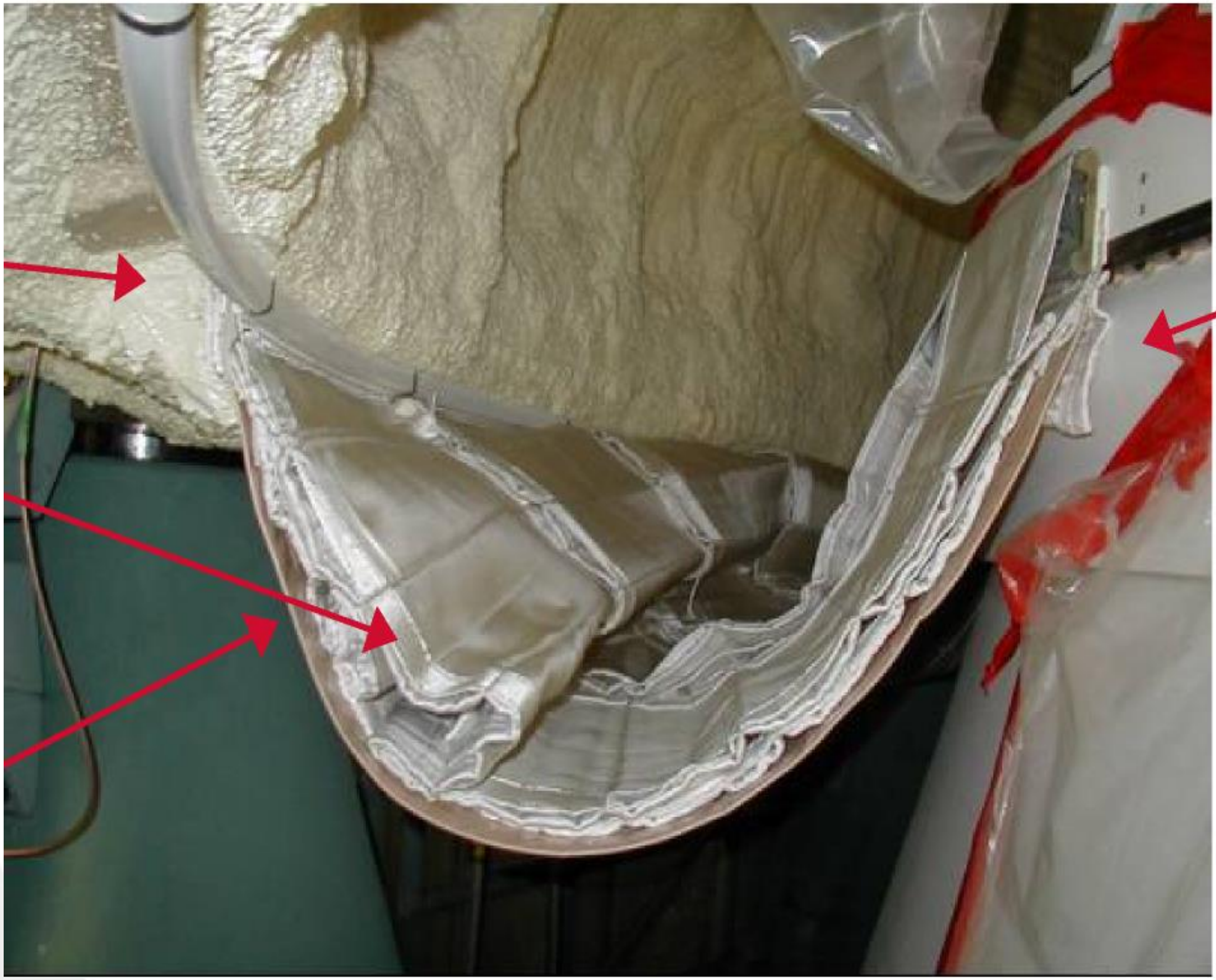
Actuator Support Bracket:
Cork



Acreage:
MCC-1

Aft Fastener Row:
MCC-1 over
Cork and BTA

SRB Thermal Curtain



Aft Skirt

RSRM
Nozzle

Inner and Outer
Blanket
Astroquartz
Fiberglass

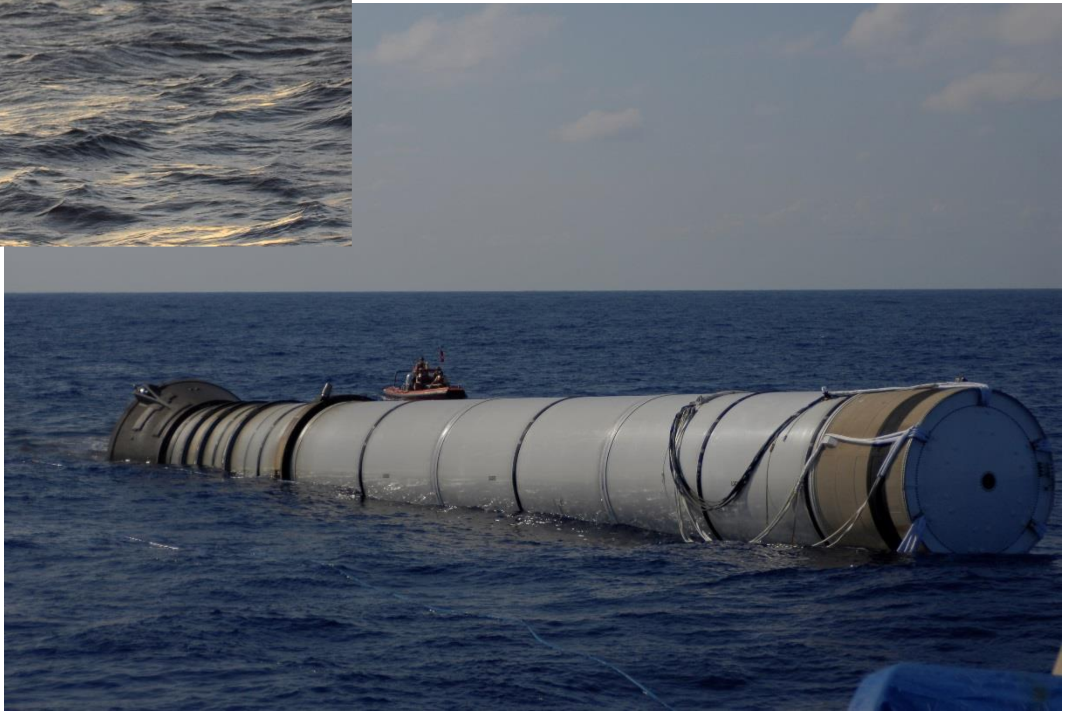
Viton-Coated
Nylon

RSRM Nozzle

Nozzle Plug Cork

Nozzle Exit Cone Cork

Post-Flight



Post-Flight

Post-Flight

Post-Flight

Post-Flight

Post-Flight

SRB components have the TPS removed, are refurbished, and are kept at KSC.

RSRM components are shipped back to Utah via train for inspection and refurbishment. The cases will be loaded with propellant and shipped back to KSC.

How Did We Get To This Point?

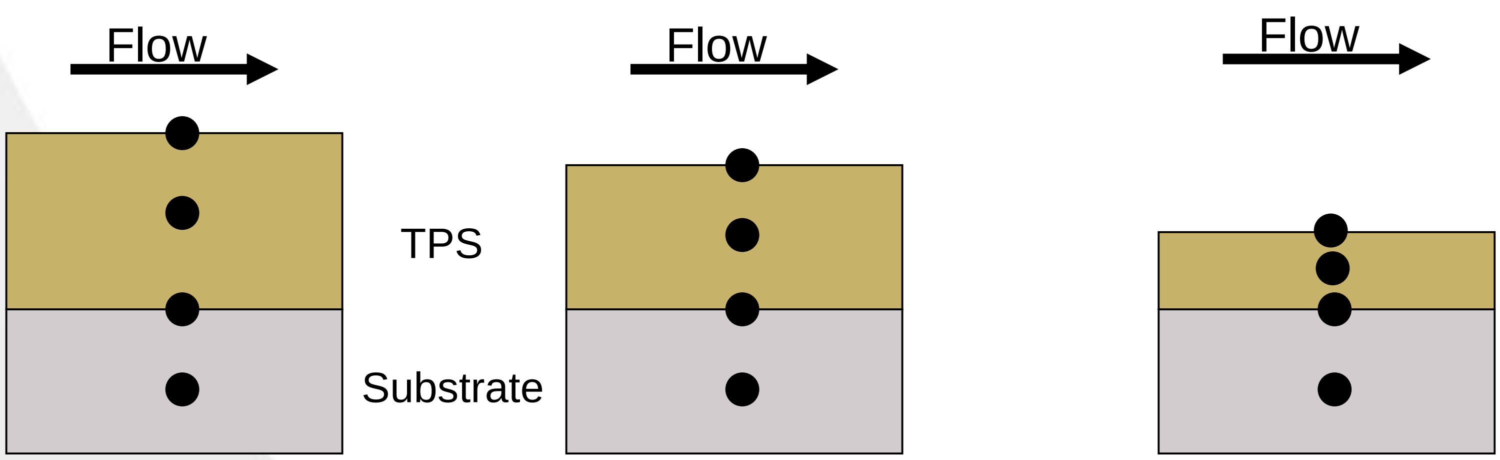
- Many factors in determining which ablative TPS to use.
  - Processing
  - Weight
  - Recession Rate
  - Insulative Properties (low conductivity, high capacitance)
  - Special Properties (RF transmissive, withstand lightning strikes, etc.)

- Typically a collaboration between Materials/Processes and Thermal to determine which materials to use in which application.

How Did We Get To This Point?

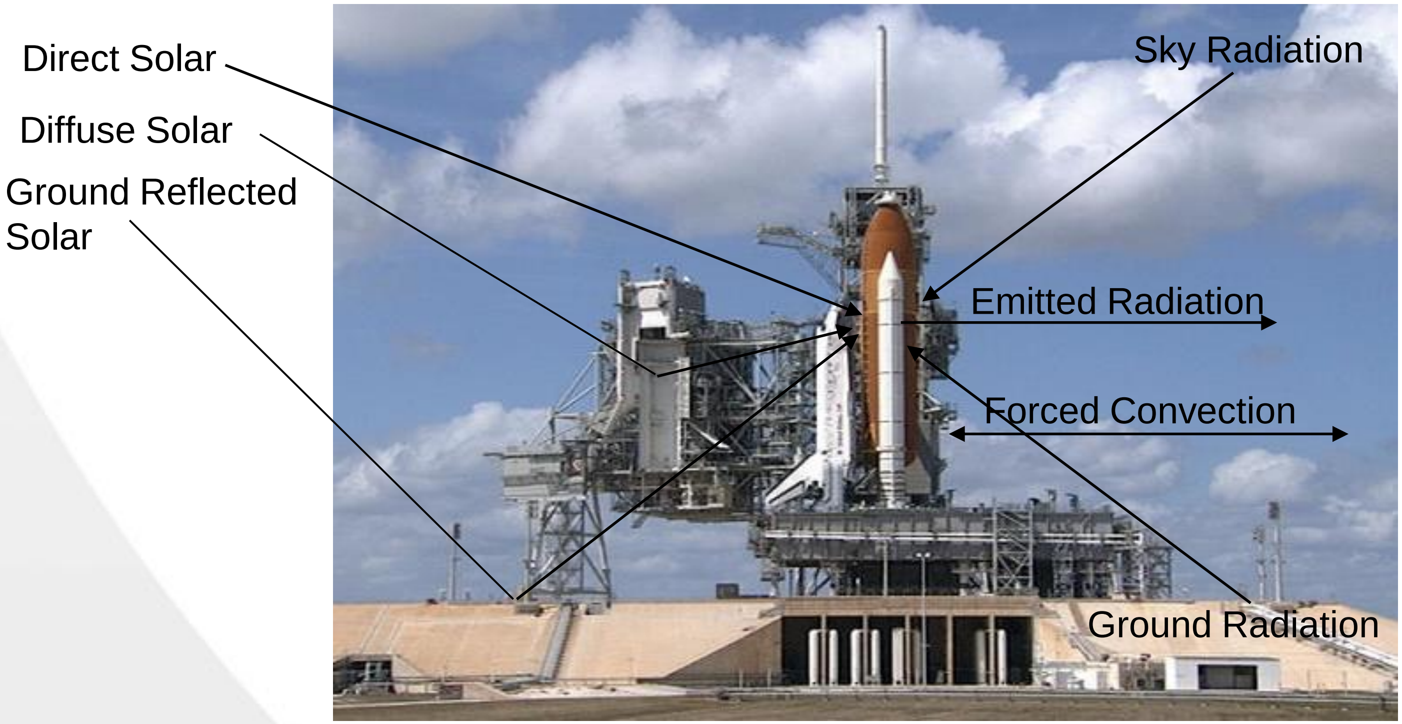
Analysis

- Once a TPS is selected, the next challenge is to determine the required thickness
  - Structural analysis determines substrate temperature limit
  - Need enough TPS to protect substrate
  - Additional TPS adds weight to component
  - With ablative materials, must account for surface ablation
    - Conductive path and thermal capacitance values change with time
    - Once a material reaches its ablation temperature, analytical surface ablation begins.



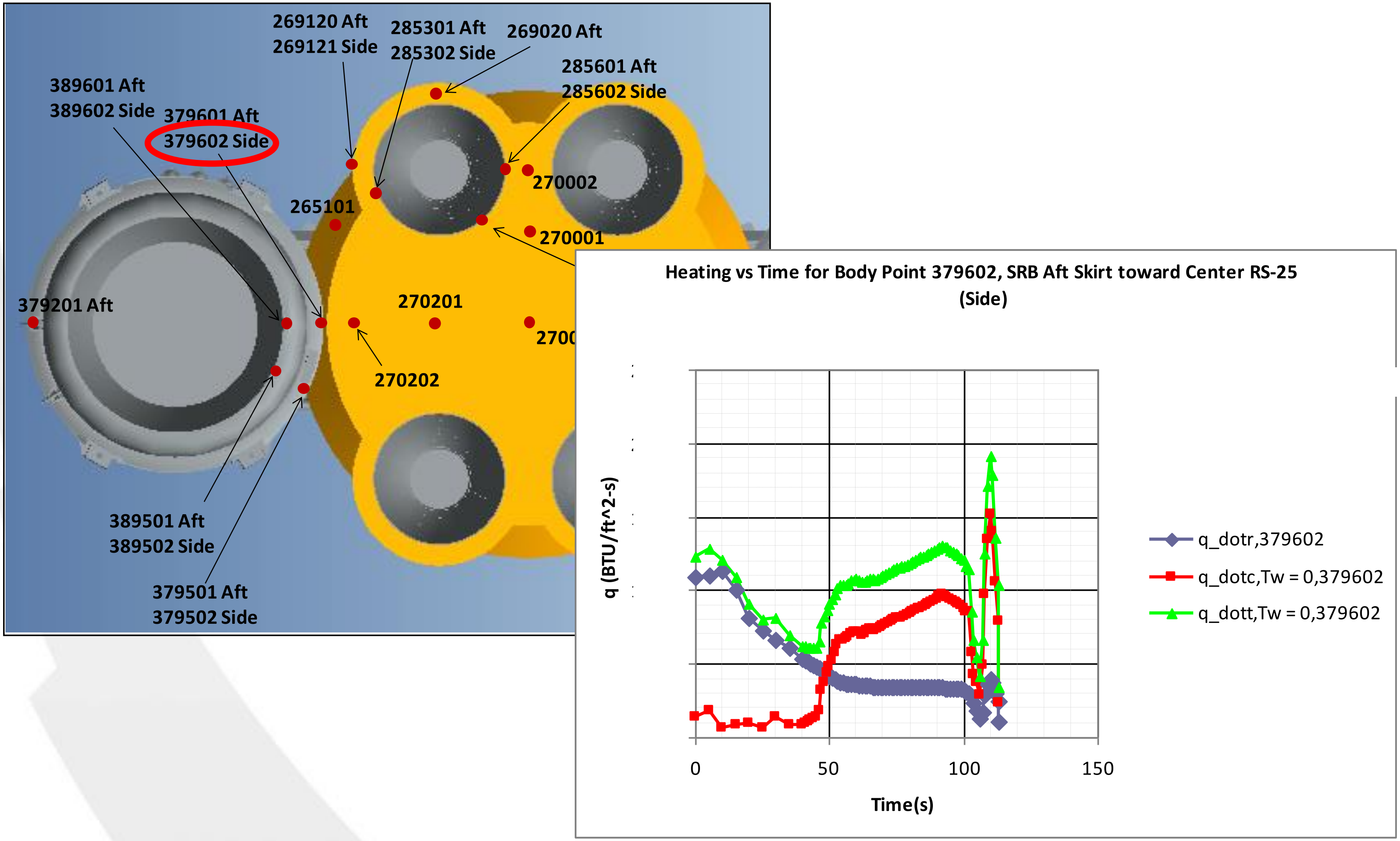
Natural Environments

- Analysis begins with applying natural environments.
  - Especially important for Cryoinsulation
  - Ambient environments will affect boil-off of cryogenic liquids
    - Also affect ice/frost formation on TPS surface
- For SRB, initial temperatures affect electronics, high-stress areas, PMBT, etc.



Induced Environments

- External thermal environments are provided by MSFC's Aerosciences Branch

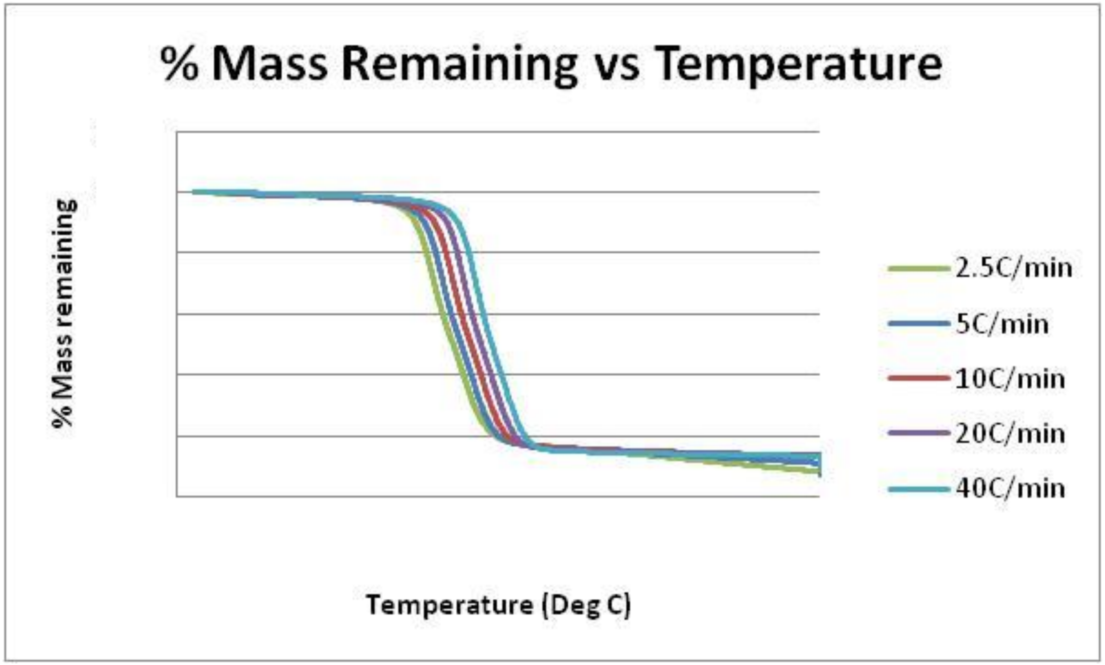


Analysis

- Data required for TPS sizing analysis
  - Geometry – MSFC's Structural & Mechanical Design Branch (EV32)
  - Materials – TPS and Substrate – MSFC's Materials Lab (EM) and EV32
  - Substrate Temperature Limit – EM and EV32
  - Natural Environments – MSFC's Natural Environments Branch (EV44)
  - Induced Environments – MSFC's Aerosciences Branch (EV33)
  - Material Properties – MSFC's Materials Lab (EM)
    - Density
    - Specific Heat
    - Conductivity
    - Absorptivity and emissivity
    - Ablation Temperature
  - TPS Recession Rate – Typically generated by a Thermal group
    - This is where we begin to differ from a true chemical ablation analysis

Thermogravimetric Analysis

- A ground sample of the material is place in the crucible.
- The crucible is heated by small furnace, typically in an inert environment.
- A balance weighs the sample as various components offgas.
- Is used to generate an ablation temperature.
  - Different criteria have been used to define ablation temperature.



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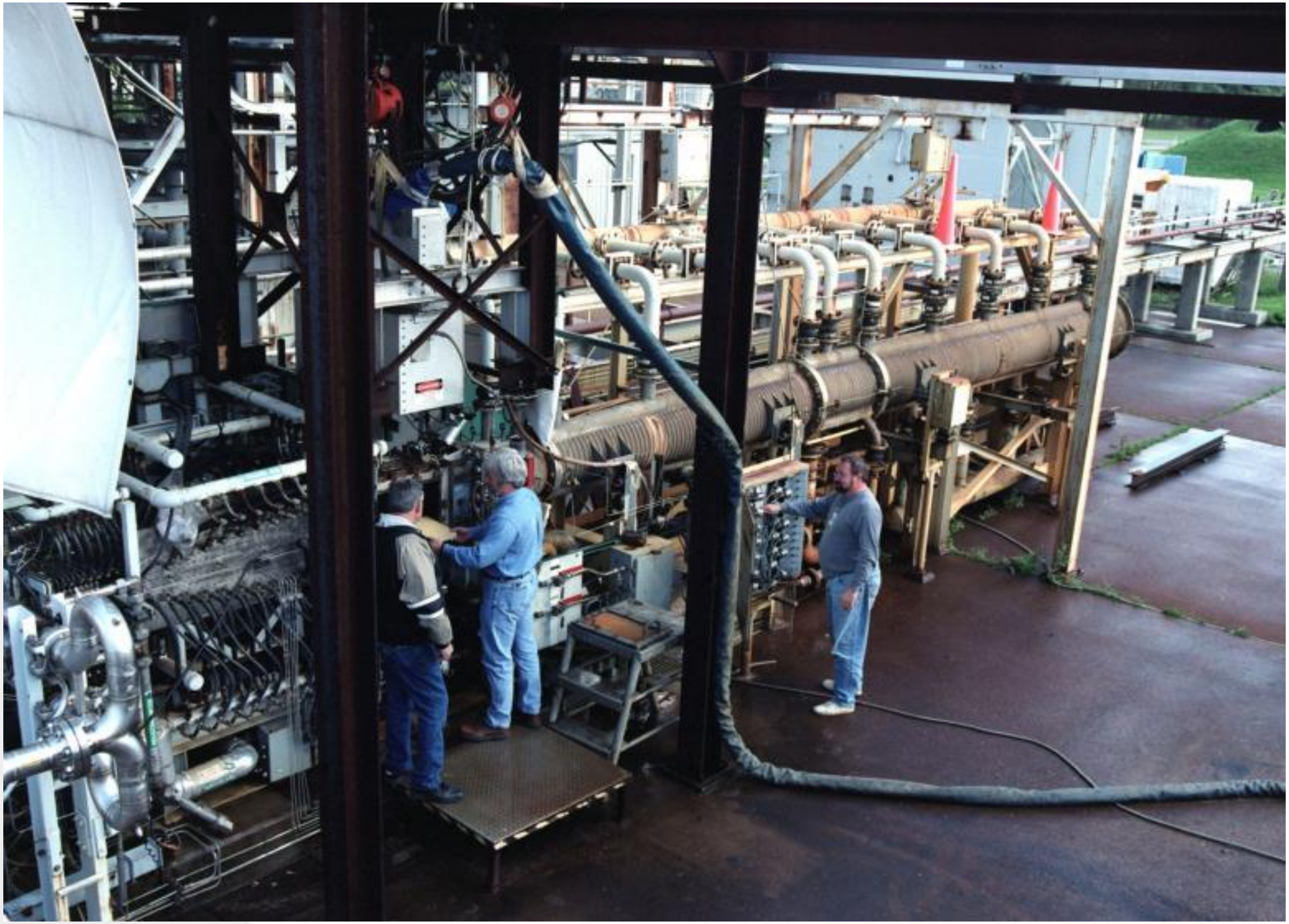
  - TPS Recession Rate – Typically generated by a Thermal group
    - This is where we begin to differ from a true chemical ablation analysis
    - Conservative process developed at beginning of Shuttle program
    - Proven methodology
    - No schedule or funding for testing required to validate chemical ablation analysis

MSFC’s Hot Gas Facility (HGF)



MSFC’s Redesigned Hot Gas Facility (RHGF1)

MSFC's Redesigned Hot Gas Facility (RHGF1)

- Mach 4 Aerothermodynamic testing facility for Thermal Protection System materials.
- Combustion driven – lean mixture of gaseous Hydrogen (GH_2) and missile grade air.
- Capable of temperatures of 1440 – 2400 ^{o}F and total pressures of 100 – 220 psia.
- 300kW radiant lamp system provides plume environment simulation. The only Mach 4 convective facility that can provide radiant environment.
- Shutter system in test section allows flow to become stable before insertion of test panel.
- Infrared (IR) thermal imaging/video capabilities allow for real-time surface temperature measurements.
- The HGF is reasonably small, inexpensive in operation, very flexible and efficient, and is operated with a small, highly experienced crew.

MSFC’s Redesigned Hot Gas Facility (RHGF1)

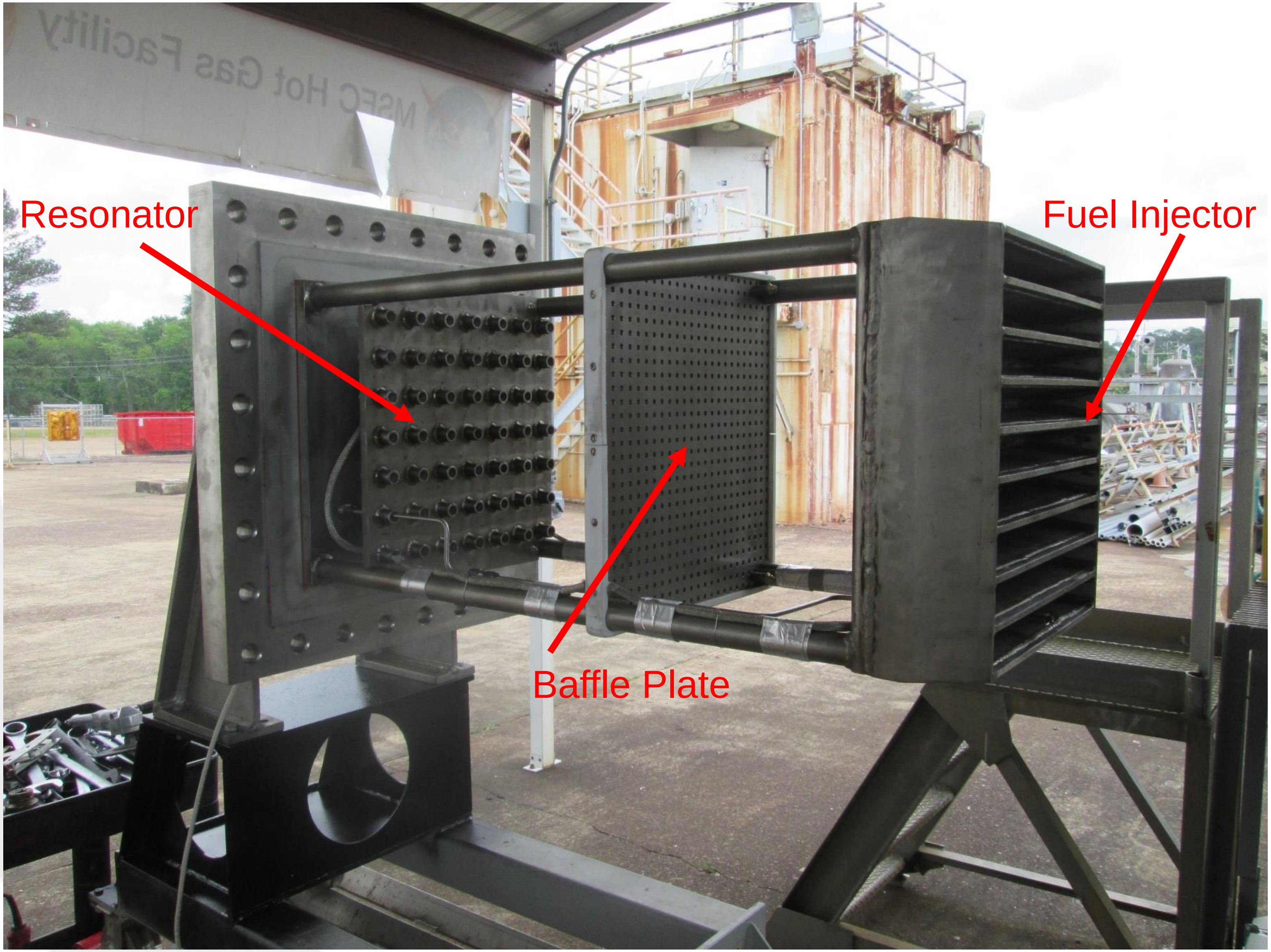
- Heritage facility dates to the 1970’s.

- Current facility was constructed in the 1980’s

- Many updates since then.
    - Improvements to the combustor to provide more uniform flow – 1990’s
    - Panel insertion system – 1994
    - 300kW radiant lamp – 1995
    - Water cooled test section – 2013
    - New combustor – 2017
    - Enlarged throat downstream of test section - 2017

MSFC's Redesigned Hot Gas Facility (RHGF1)

New Combustor



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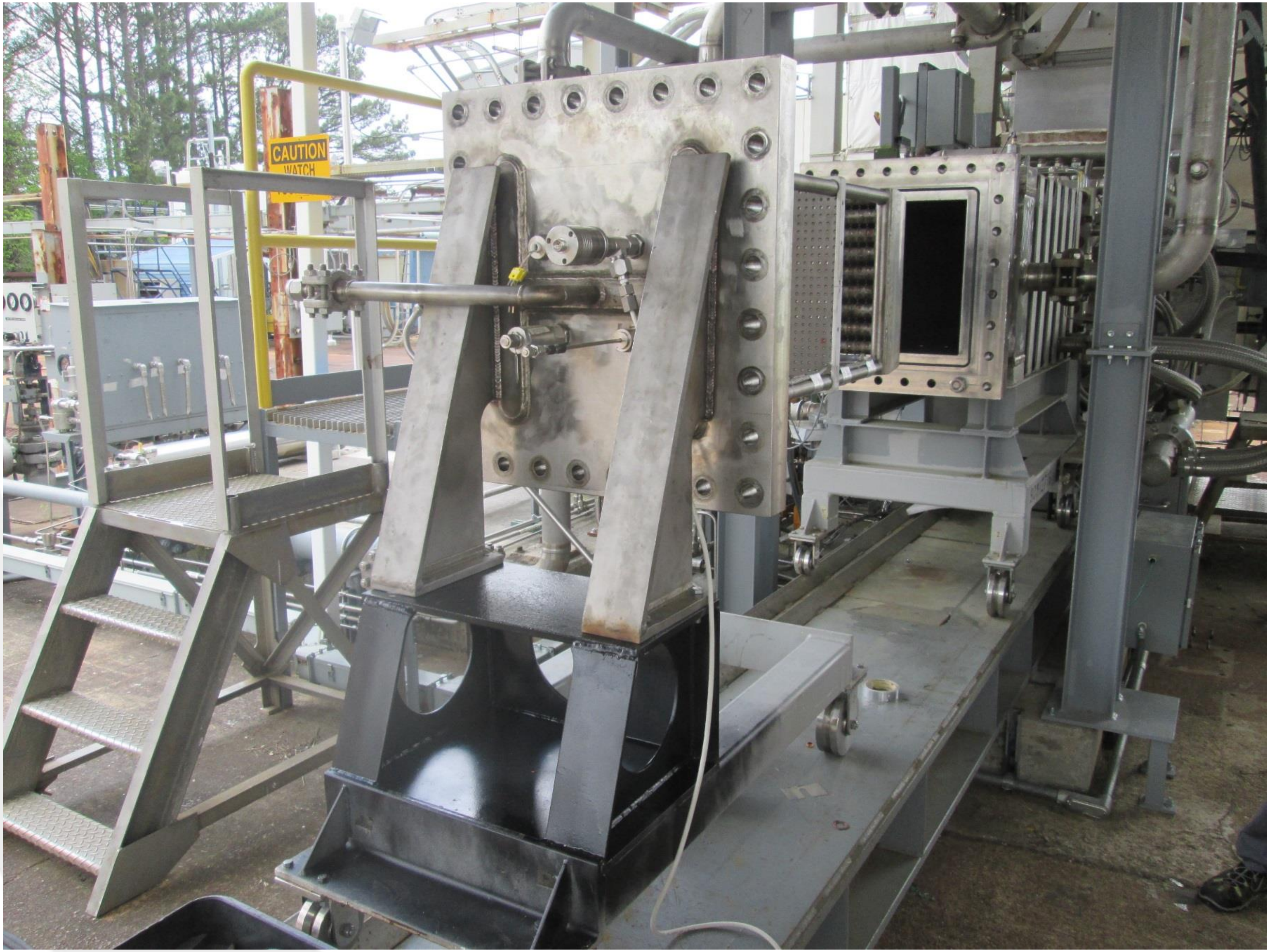
New Combustor



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New Combustor

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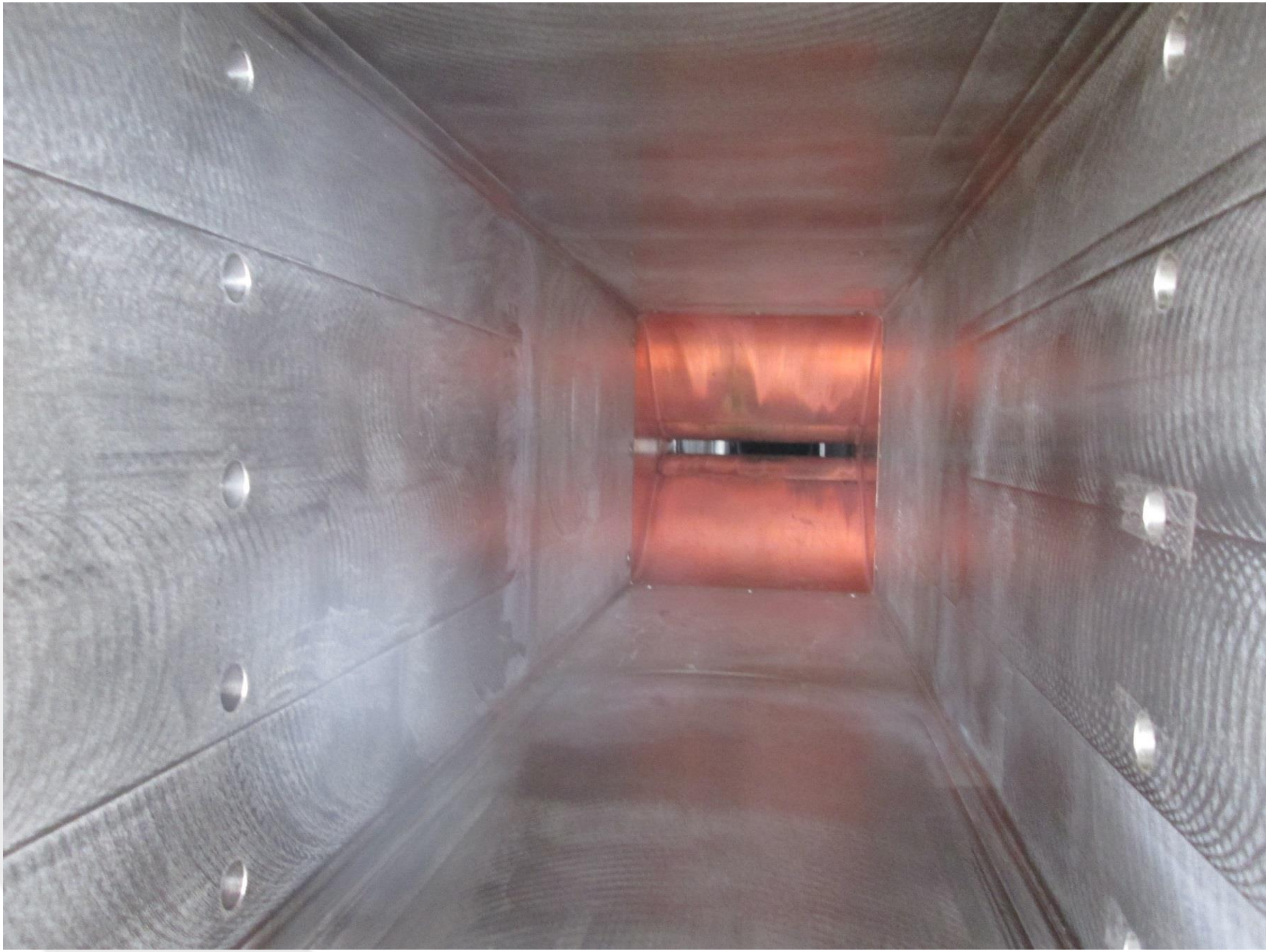
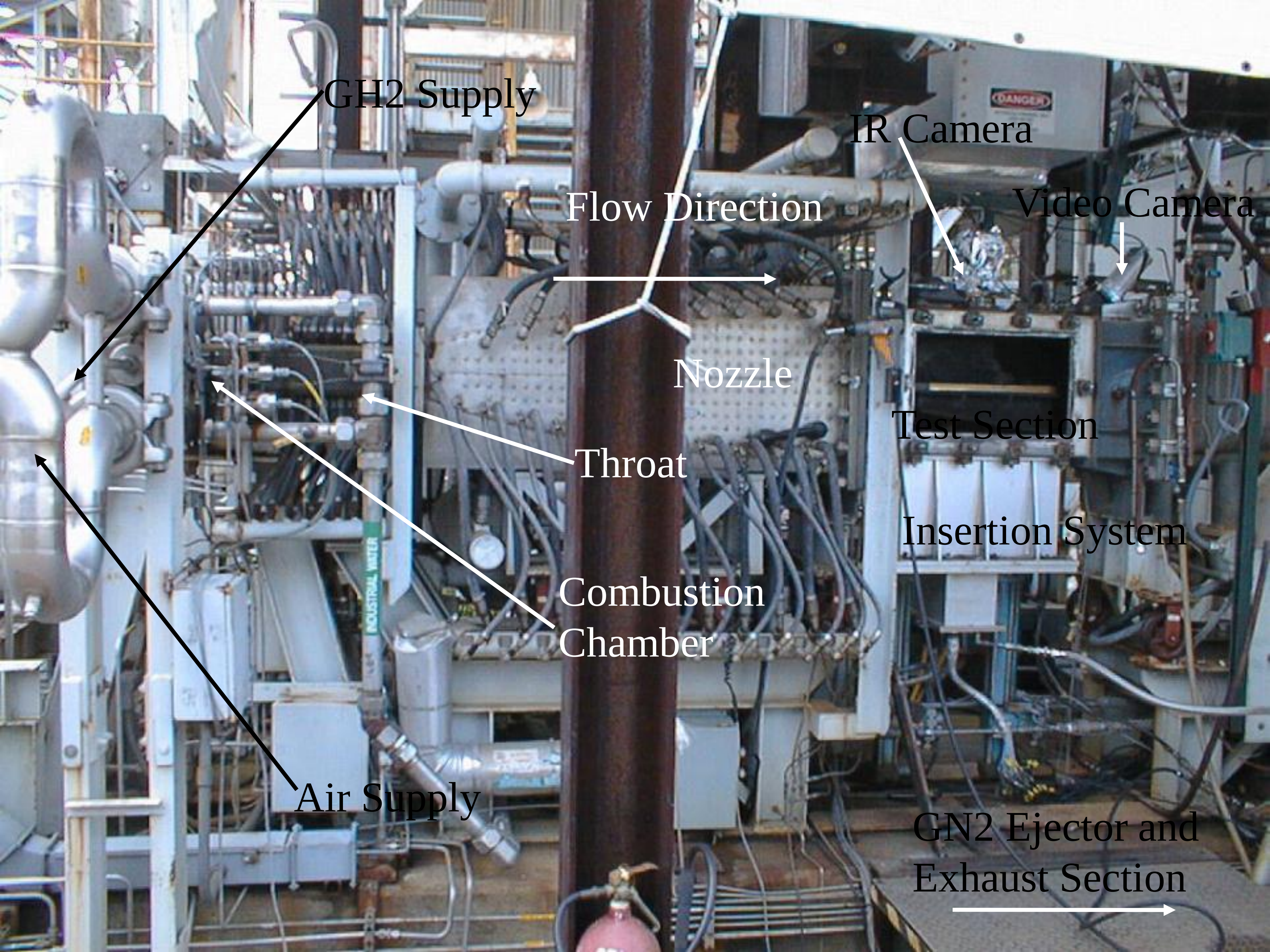
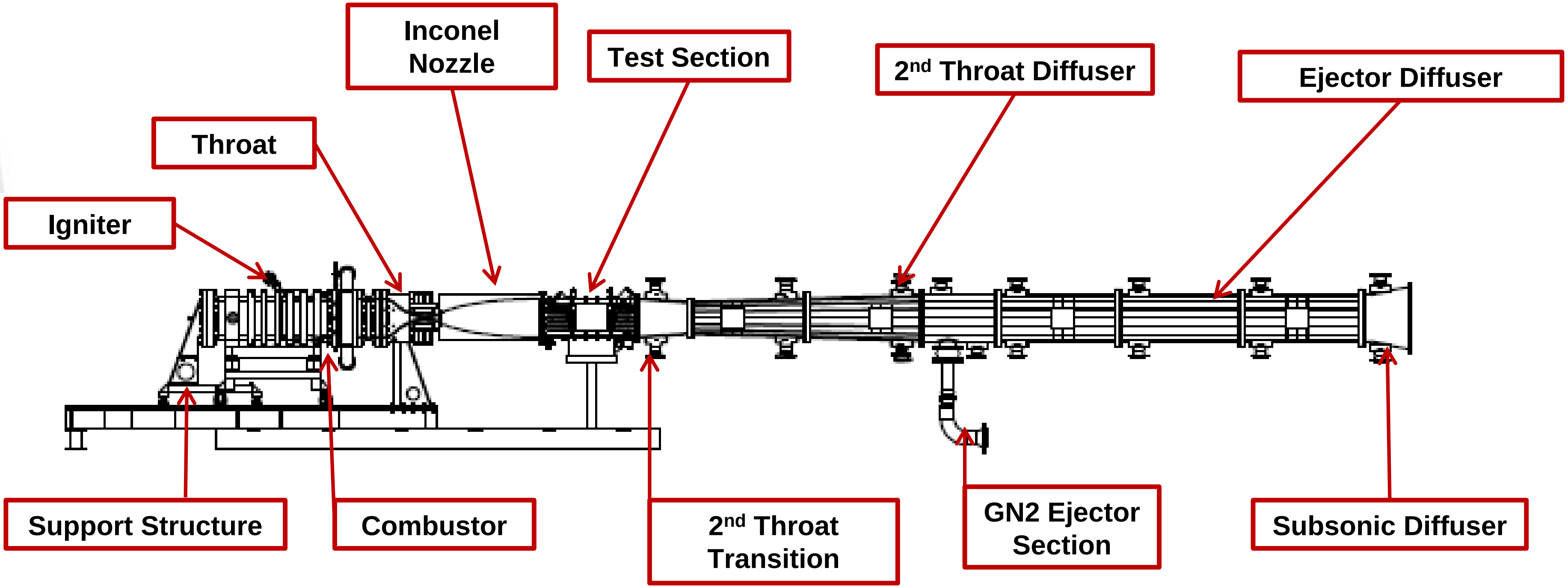


MSFC's Redesigned Hot Gas Facility (RHGF1)

Picture of test section


GH2 Supply
IR Camera
Flow Direction
Video Camera
Nozzle
Test Section
Throat
Insertion System
Combustion
Chamber
Air Supply
GN2 Ejector and
Exhaust Section

MSFC's Redesigned Hot Gas Facility (RHGF1)



Purpose of RHGF1

- Data required for TPS sizing analysis
  - Geometry – MSFC's Structural & Mechanical Design Branch (EV32)
  - Materials – TPS and Substrate – MSFC's Materials Lab (EM) and EV32
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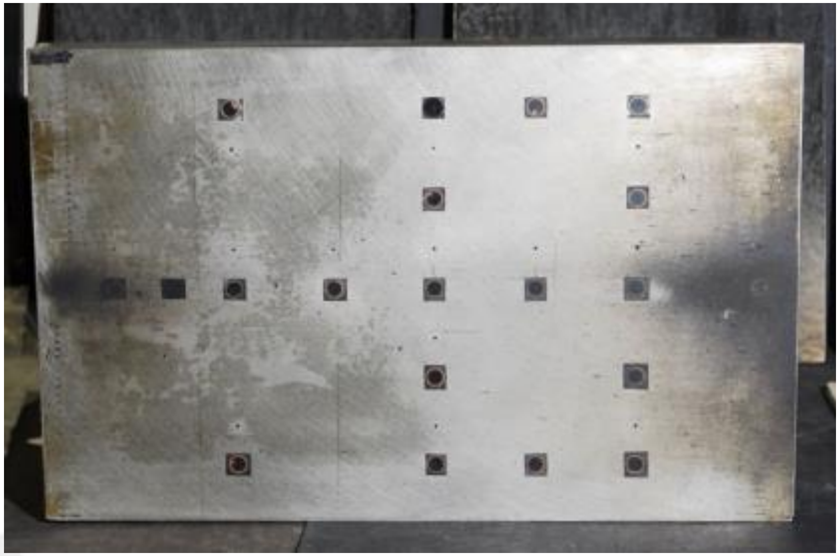
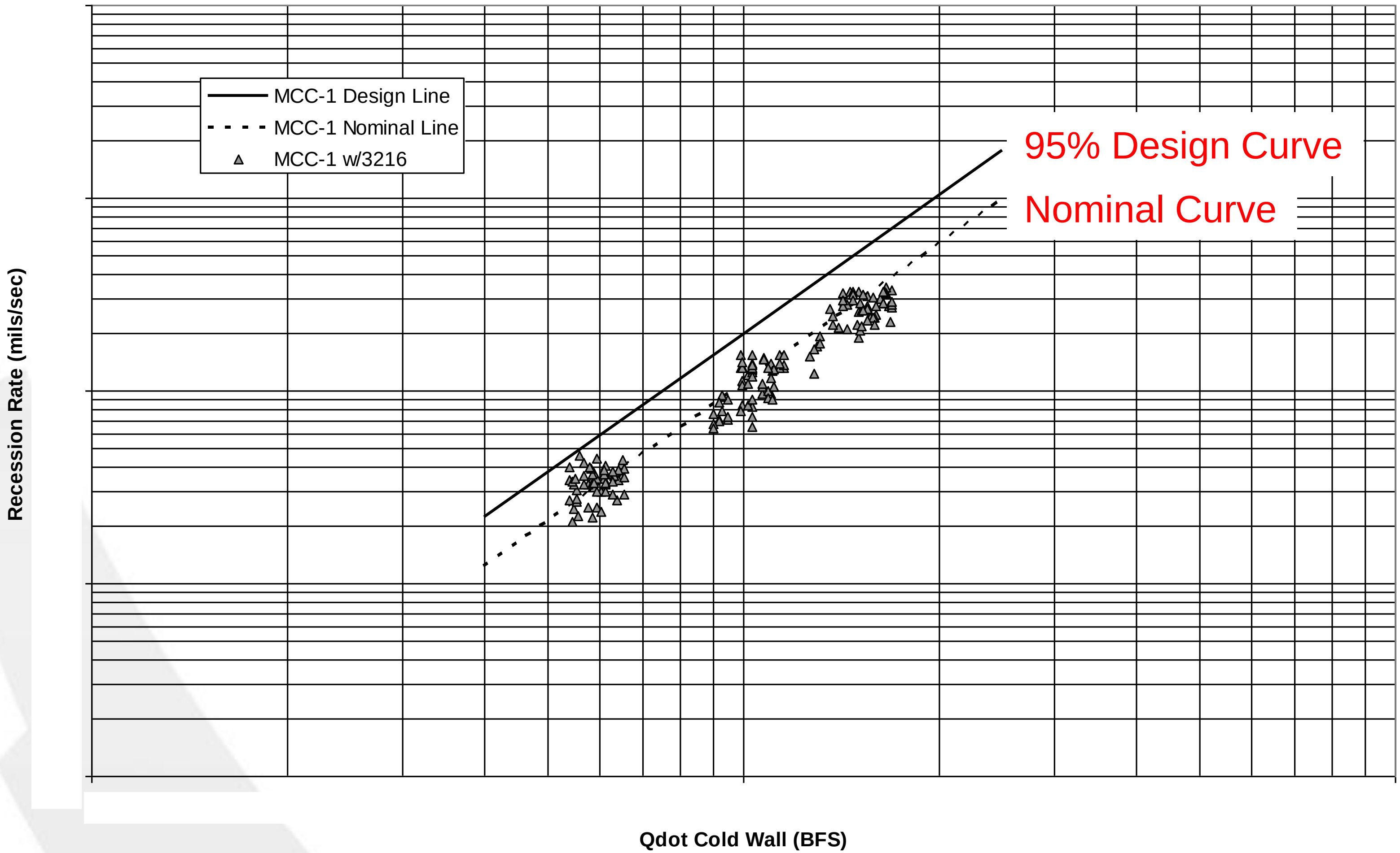


Scraping Process

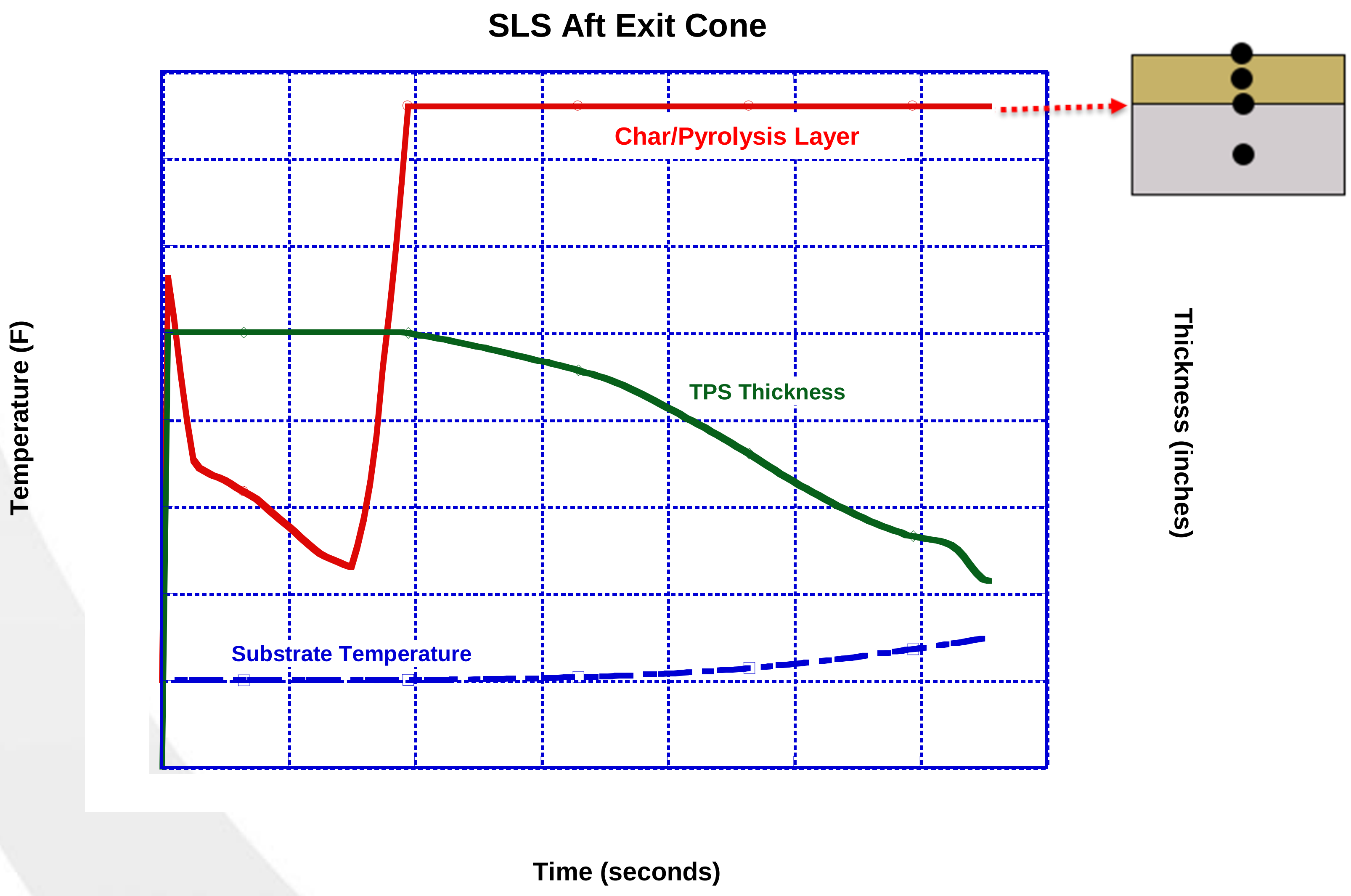
Scraping Process

Recession Rate Curve

$$Rdot = a*qcw^{b}$$



Analysis Results



Conservatisms in SRB TPS Sizing

1. Continous Mach 4 shear environment in test facility
2. Removing char before post-test measurements
3. The RHGF1 generates enthalpy levels higher than flight. Testing has shown that a higher enthalpy at the same heat rate will generate more recession
4. These parameters generate a conservative recession. We then generate a 95% design equation for analysis
5. And use a 99.7% Aeroheating flight environment for analysis
6. Analysis assumes total loss of material at ablation temperature. Does not account for insulative properties of remaining char
7. Recession rate does not account for effects of paint. Nor are the thermophysical properties of paint used in analysis.

This is why…..

We look like this in testing

And this in post-flight

Why Don't We Change

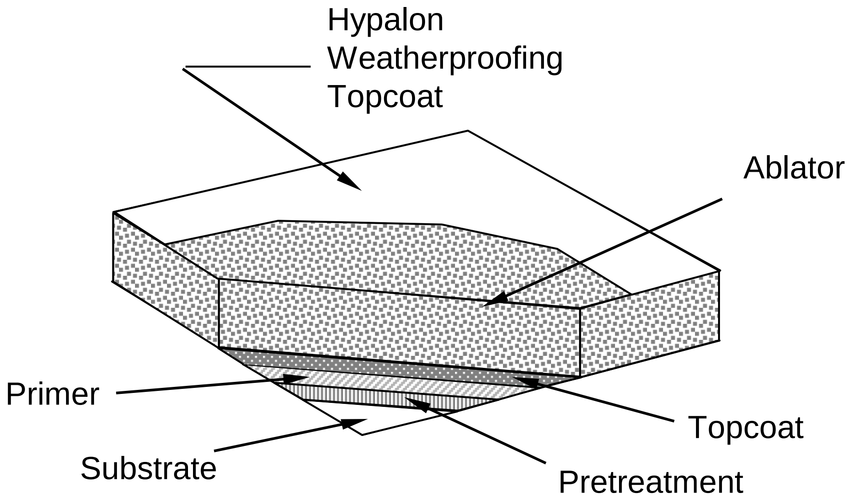
- Conservative process developed at beginning of Shuttle program
- Proven methodology
- No schedule or funding for testing required to validate chemical ablation analysis
- Conservative approach adds mass, but at a lower complexity
  - 10-1 payload mass ratio for SRB.
- The cost trade-off of developing a fully characterized TPS multi-environment ablation test program was chosen at the expense of mass.

Still More Testing

- Most of the time, more, specific testing is required.
  - Non-Thermal environments
  - Specific design issues
  - In-Flight anomaly
  - Material changes

Qualification Testing

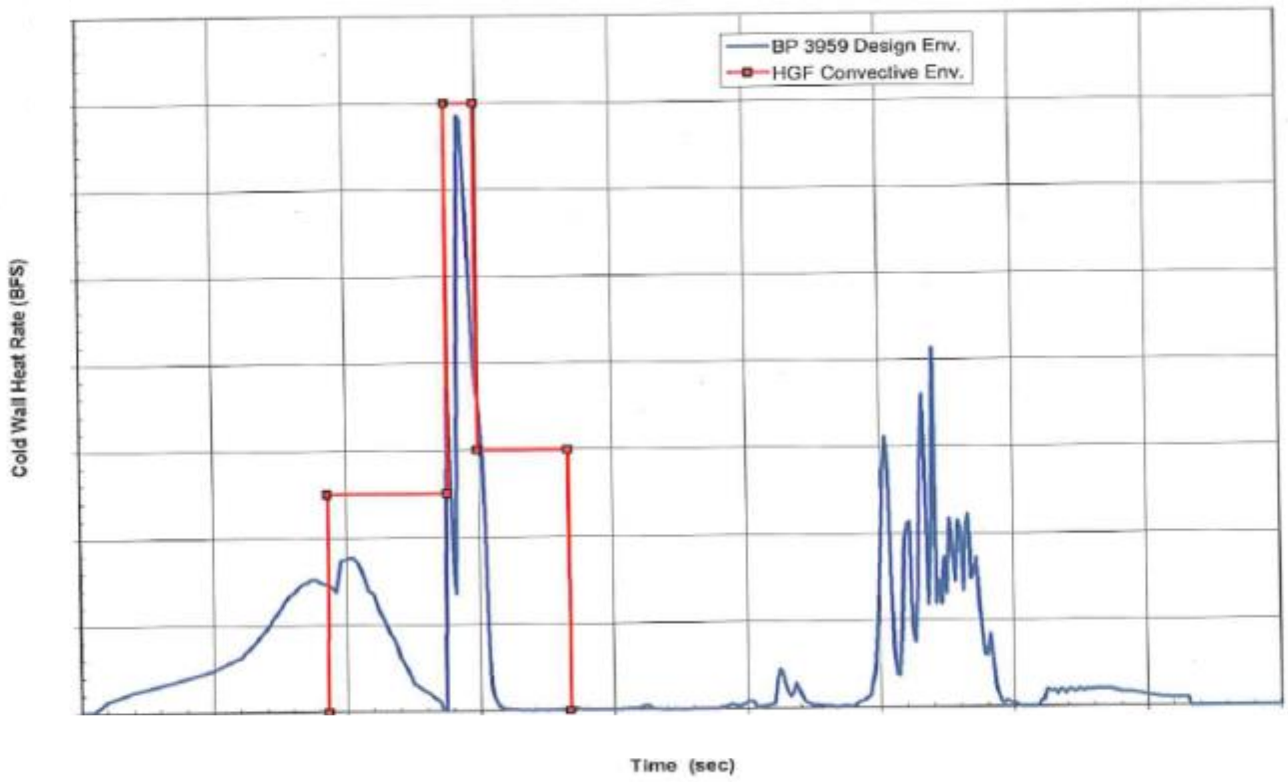
- Once we have determined desired TPS material and thickness we do verification and qualification testing.
- Previous testing determined a recession rate for specific TPS materials. Qualification testing is focused on testing the entire TPS system at expected flight environments.
- Verification and qualification testing will ensure that the combination of all materials in the Thermal Protection System will not degrade the overall performance.



Qualification Testing

- The RHGF1 cannot match the exact flight aeroheating profile.
  - The intent is to match the peak heat rates and integrate load.

- Again, the intent is to be conservative, not exact.



Qualification Testing

- If the TPS material is new, or the testing involves a material obsolescence issue, the TPS is still not qualified for use on a flight vehicle.

- There are several requirements for TPS on a flight vehicle.
  - Shock/Vibration
  - Fungus
  - Humidity
  - Lightning
  - Ice/Hail
  - Flora/Fauna
  - Rain
  - Salt Fog
  - Sand/Dust
  - Solar Radiation/Ultraviolet
  - 180 Day Pad Stay

- Fortunately, most of these requirements are met by Beach Exposure Testing

Beach Exposure Testing

- Painted qualification test panels are placed on stands near the beach
  - Typically for 180 days
  - Panels are monitored occasionally to document degradation
  - Panels are brought to RHGF1 for testing
  - Pass/Fail requirement is no increase in recession or debris generation

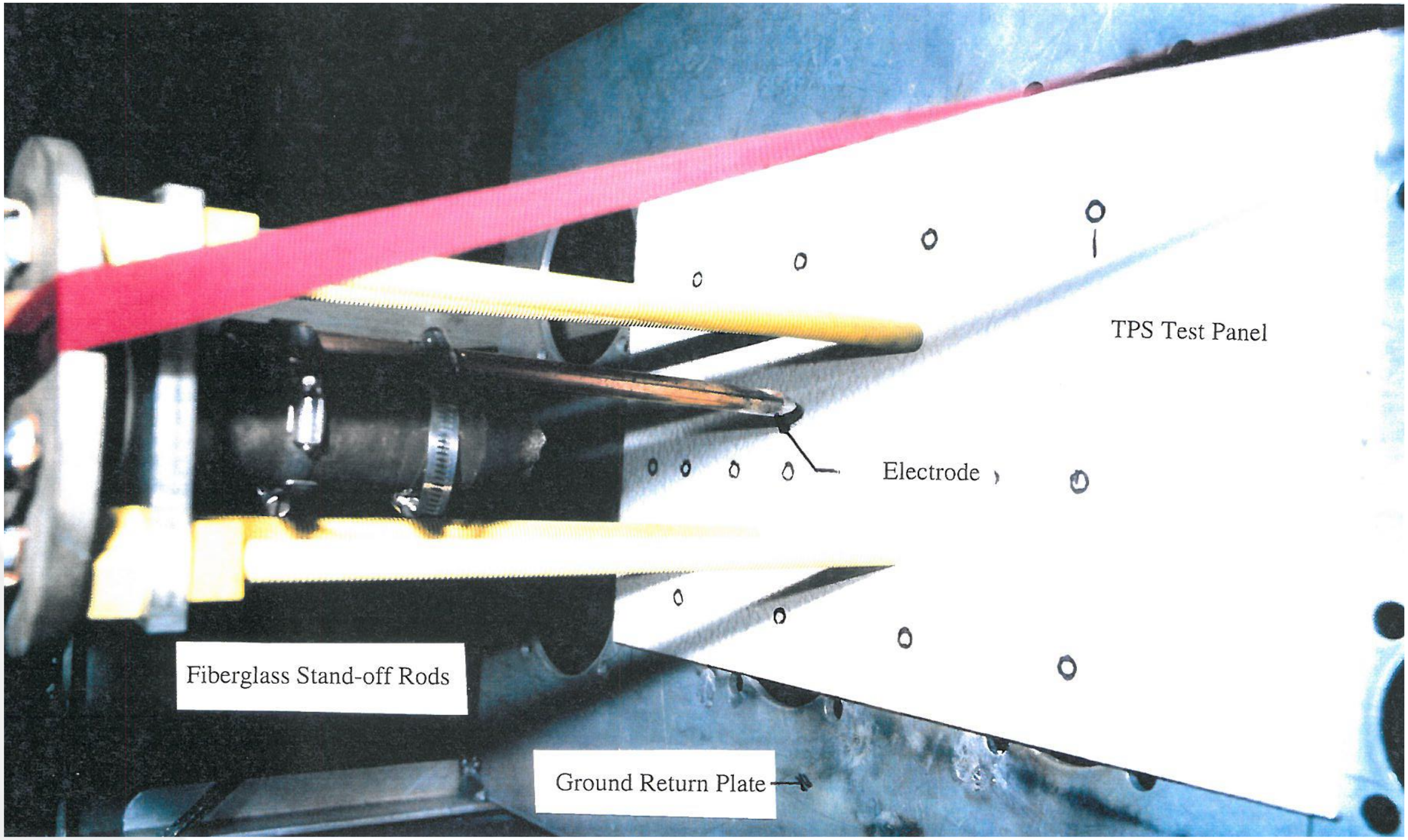
Lightning Strike Testing

- Ensure effects of impact does not generate secondary debris
- Ensure substrate temperature limit is not violated

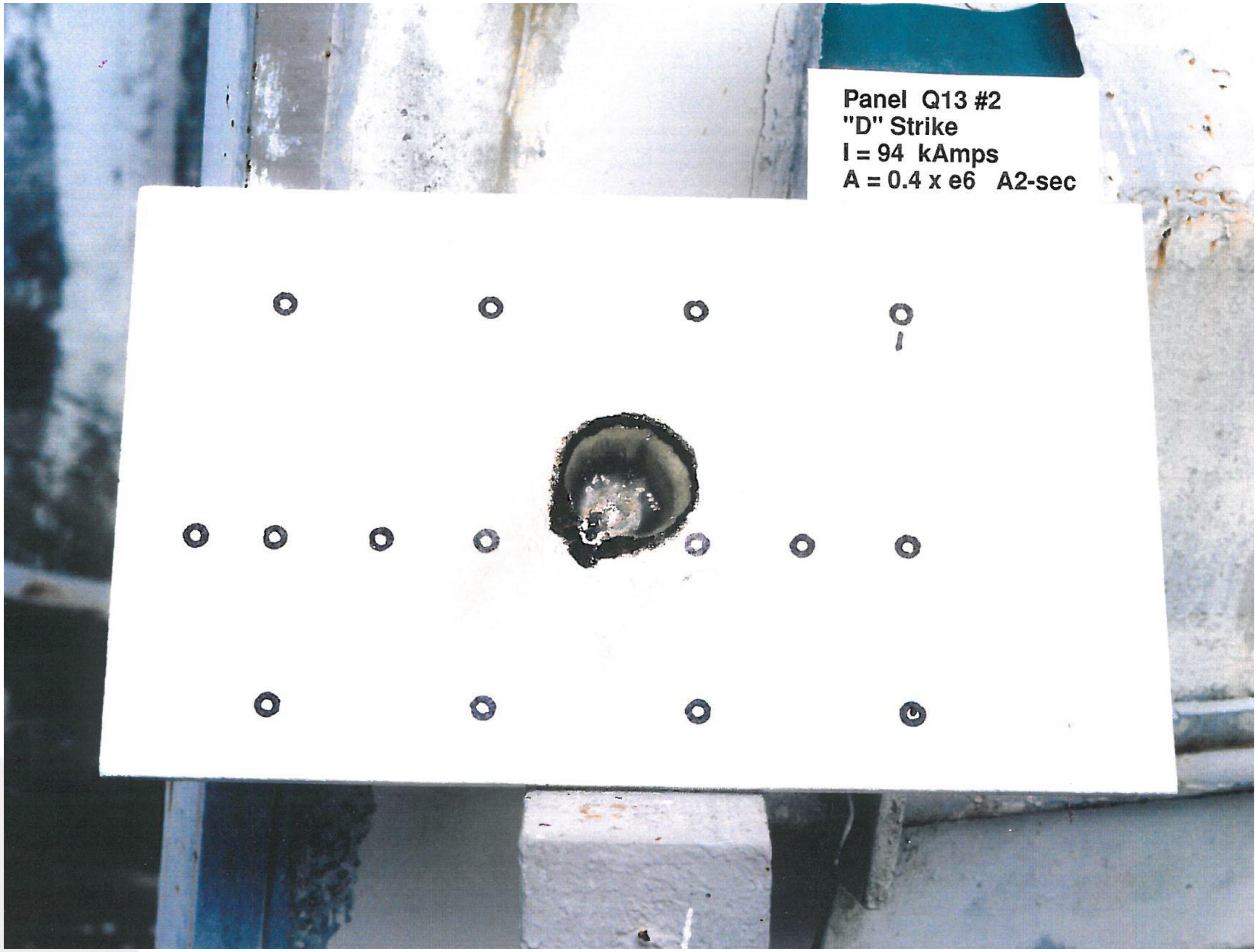
Lightning Strike Testing

High Energy Lightning Simulator – Redstone Technical Test Center

Lightning Strike Testing

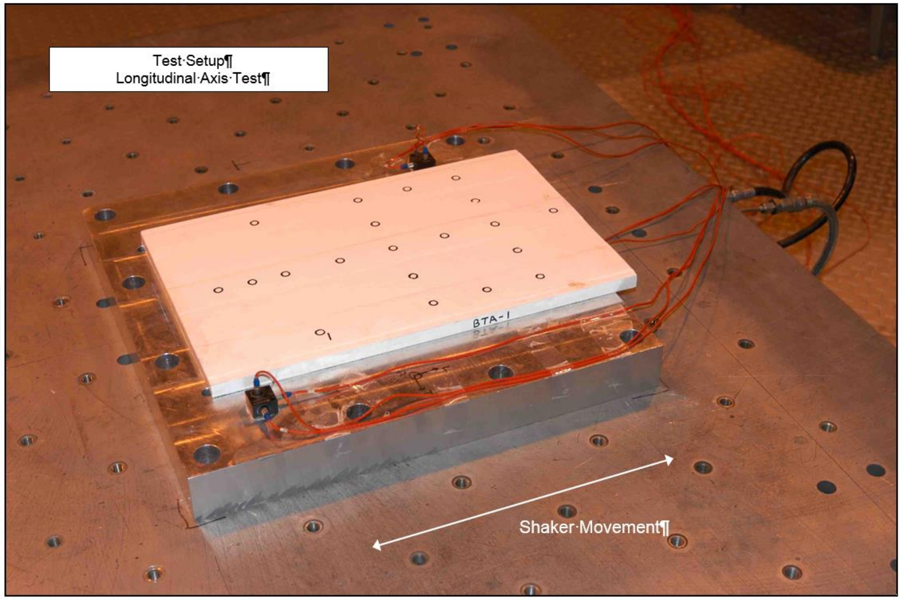


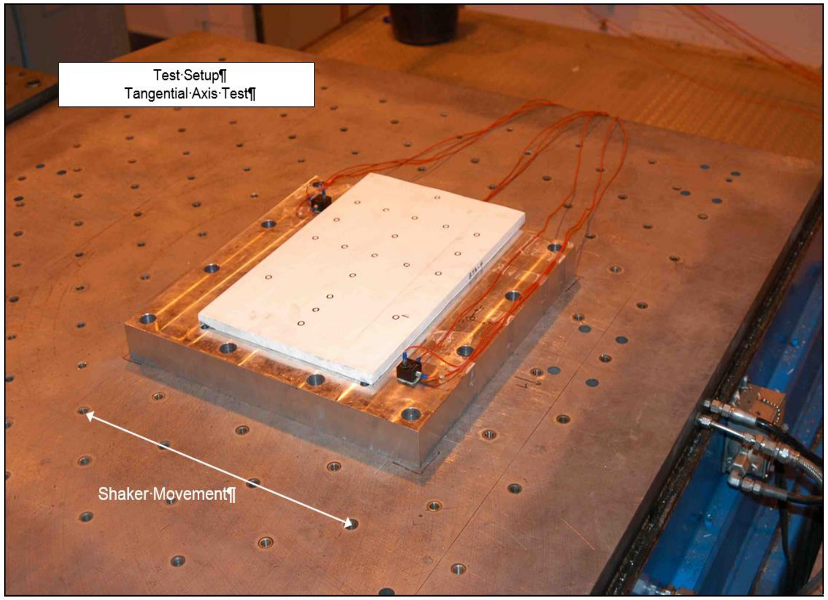
Lightning Strike Testing



Vibration Testing

- Ensure TPS system can withstand flight vibration environments
  - No degradation of materials
  - No debonds generated
  - No debris

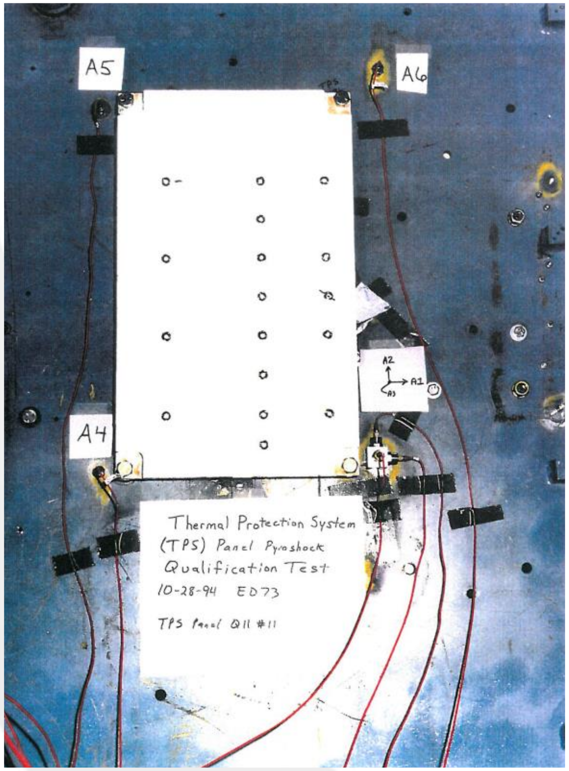




Pyro Shock Testing

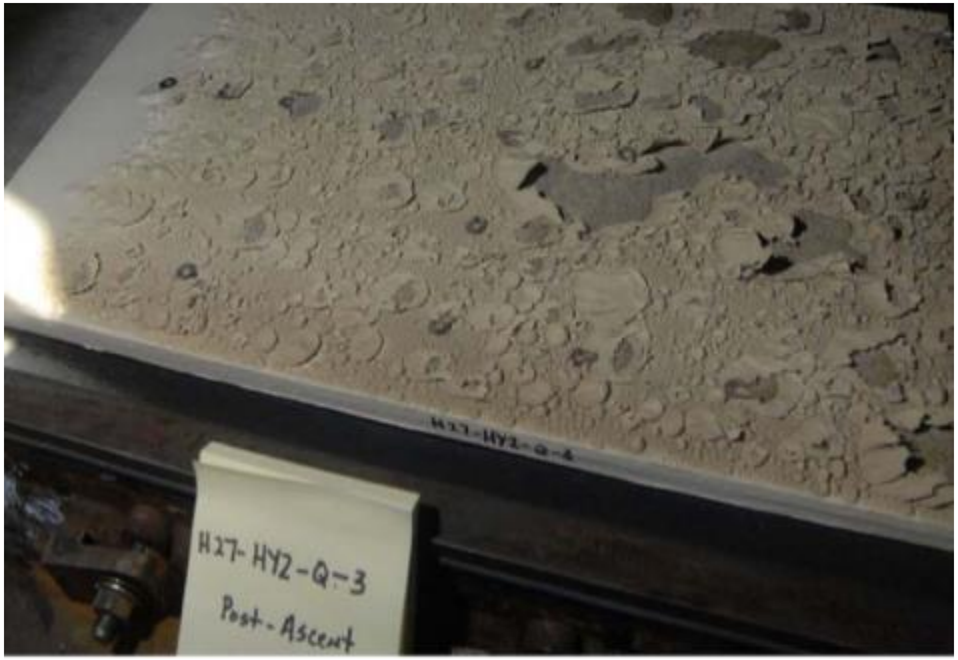
Pyro charges are placed on the back of a steel plate with a RHGF1 panel bolted to it.

TPS panel will be taken to RHGF1 and tested to ensure no hidden TPS cracks or debonds from the substrate.



Debris Generation Testing

- RHGF1 can be used to determine the likelihood of debris generation
  - Typically the facility is not conservative for debris generation
  - Debris is generated by increasing pressure in a void
  - Must have time for pressure to build before void is exposed
  - Low heat rate, long duration testing is more conservative for debris generation
  - Because of high shear environment, voids tend to vent before enough pressure can build up

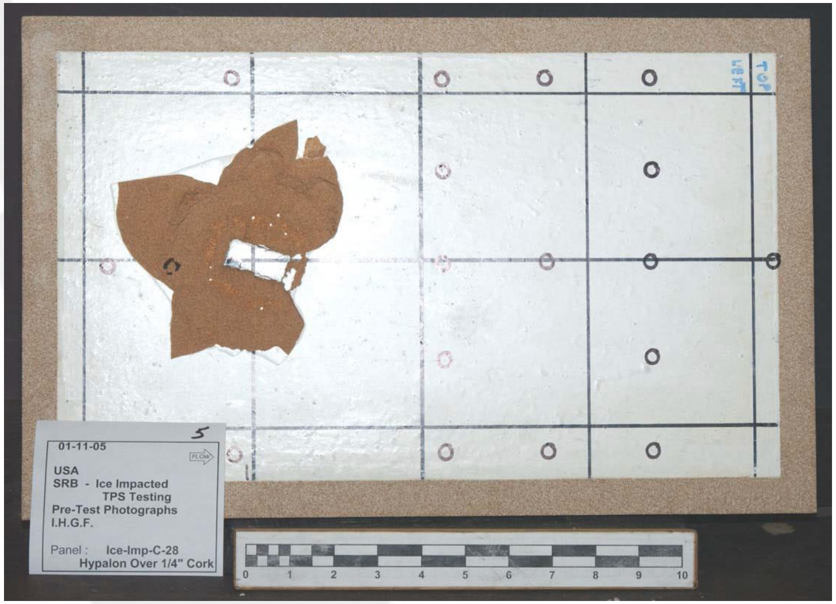


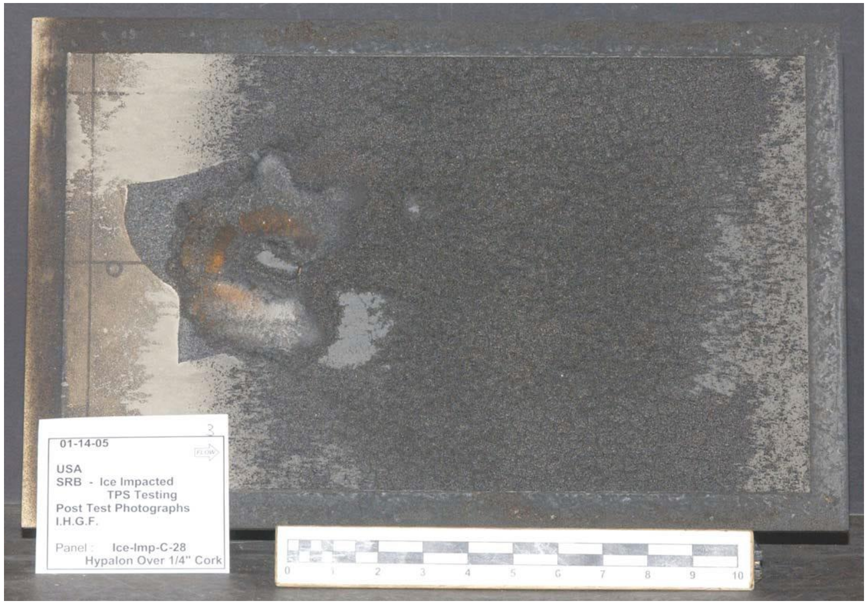
Debris Generation Testing

Post-Flight observation of cork “spalling”

Debris Impact Testing

- After the Columbia accident, all TPS materials were tested for debris impact effects
- Photos of cork after ice impact testing.
    - Ensure impact doesn't generate secondary debris
    - Ensure substrate temperature limit is not violated





Age Life Testing

- Most components of TPS materials have shelf life limits and cannot be used past that date.
- However, the expectation is that, once the material has been sprayed, or mixed, it is stable.
- This was not too bad of an assumption during shuttle operations.
- For SLS, Booster hardware is already being processed.
  - MCC-1 sprays are expected later this year.
- With current schedule, it could be two years before material flies.
  - Longer for EM-2.
- Currently, all TPS materials and topcoat combinations are undergoing Age life testing.
  - Panels are stored in a controlled environment until approximately 6 months prior to test.
  - Spend next 6 months at the Beach Exposure Facility.
- Zero Time (baseline) panels have already been tested
  - Will test at 3 and 6 years for Florida TPS/paint/bond systems
  - Will test at 2, 5, and 8 years for Utah TPS/paint/bond systems

Material Obsolescence Issues

- Over the past 40 years of using the same TPS materials, vendors change components.
  - When we are aware of it, we need to test to ensure the change had no effect on TPS ablation performance.
    - Clay used in catalyst in RT-455 component
    - Vendor that makes component used in RT-455 closes.
    - Facility changes

- Also have concerns when components are out of spec.
  - They may be close enough that a problem is not expected, but must test to verify.
    - Amount of “fines” in ground cork
    - Too much bark in ground cork
    - Too much moisture in ground cork
    - Sprayed MCC-1 density is too low

More Testing

- If the TPS passes all of the described testing, it is now qualified for use on a flight vehicle.
    - We often say that if it can pass our testing, it won't have any problem flying on a vehicle.

- However, there are times when more testing is required.
    - There are times that the TPS is exposed to an environment that is unique and is not adequately enveloped by existing testing.
    - Testing is not cheap, but it is cheaper than an In-Flight Anomaly (IFA) investigation.
    - Don't fly on a "gut feel".

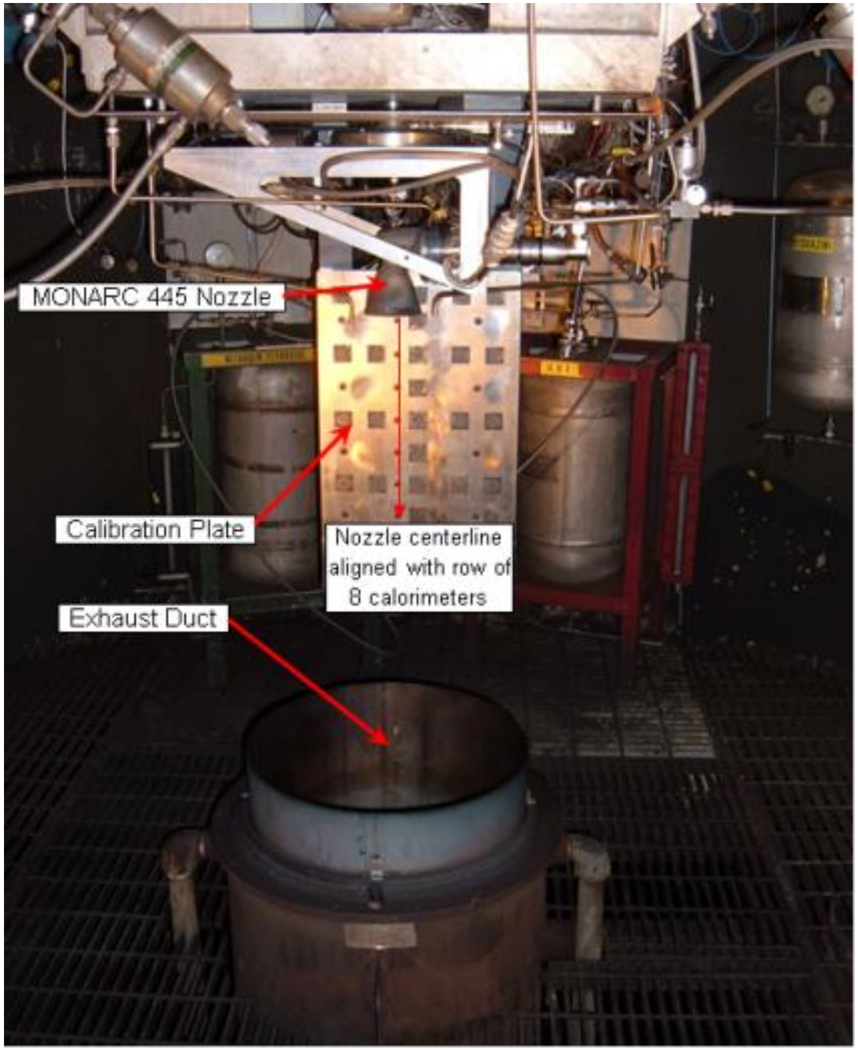
More Testing

- For the Ares vehicle, Hydrazine exhaust plumes from Roll Control and Reaction Control thrusters would impinge on Cork and NCFI Cryoinsulation.
  - A search of historical data did not uncover and information on how Hydrazine exhaust plumes would affect TPS.
    - Shear levels
    - Chemical incompatibility
    - Effect of duty cycle

- The TPS needed to be tested in an actual thruster plume.
  - Ensure recession rate curve was as good as, or better than, heritage data.
  - Didn’t want to under design TPS thickness

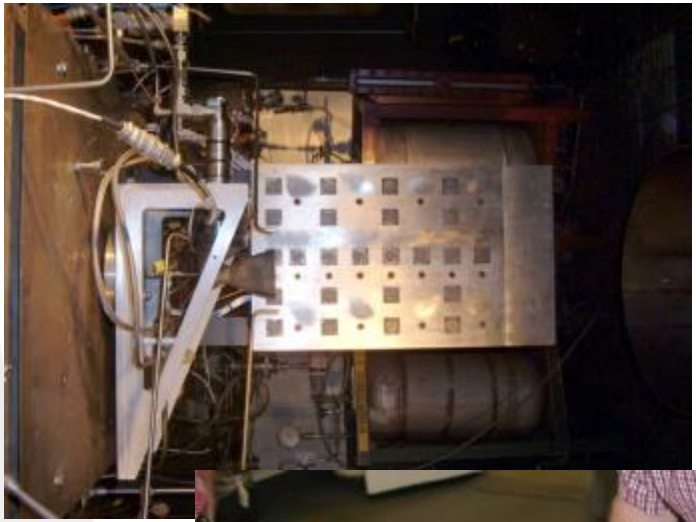
More Testing

- Reaction Control testing was performed at the AMPAC test facility in Niagara Falls, NY
- Used a MONARC 445, 100 lbf thrust monopropellant Hydrazine thruster
- Generated 0 – 25 BTU/ft2 sec
- Constant heat rate – compare to heritage recession rate.



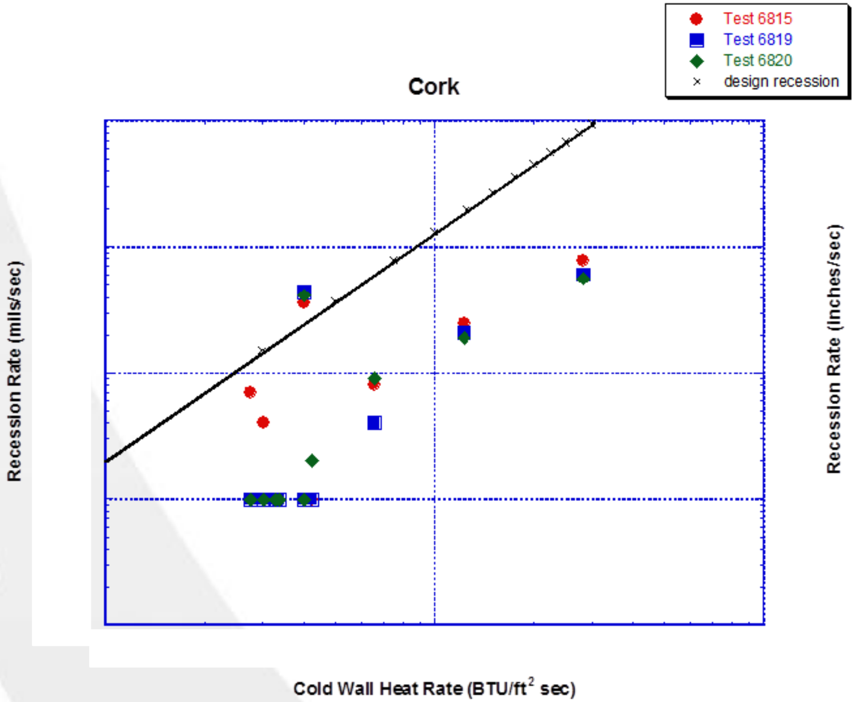
More Testing

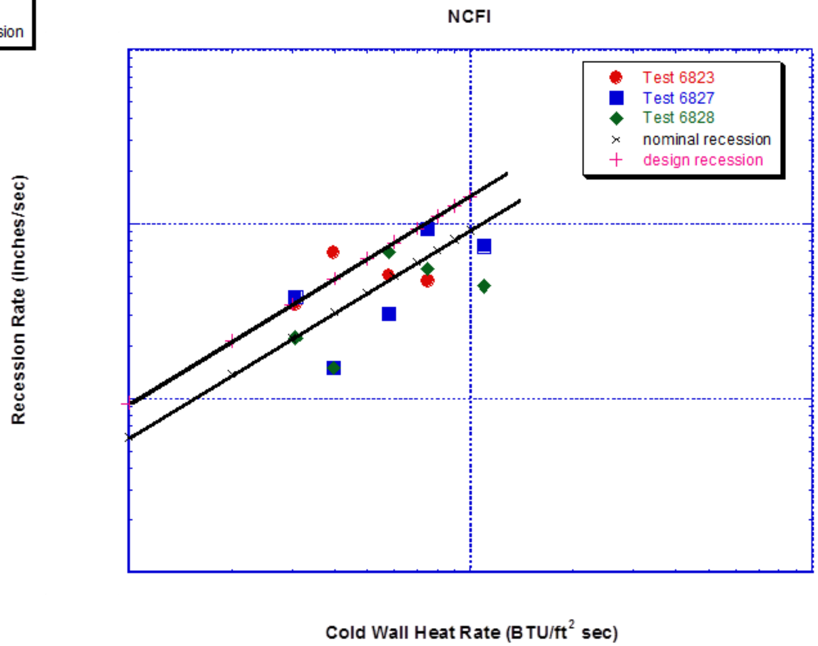
Same process as RHGF1: Calibration, Test, Measure, Scrape, Measure



More Testing

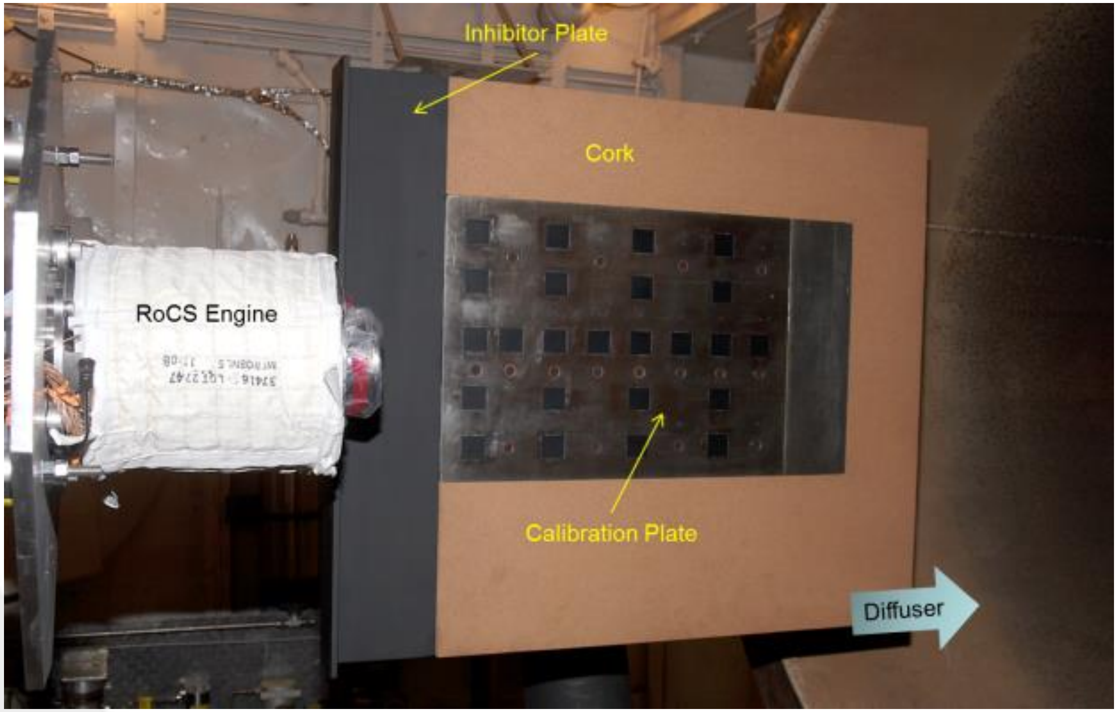
- Cork ablation was less than historical database
- NCFI 24-124 was similar to historical database
  - Surface roughness makes measurement difficult. With small recession thickness, measurement errors are magnified.
- Overall, analytical uses of existing recession rates are conservative.



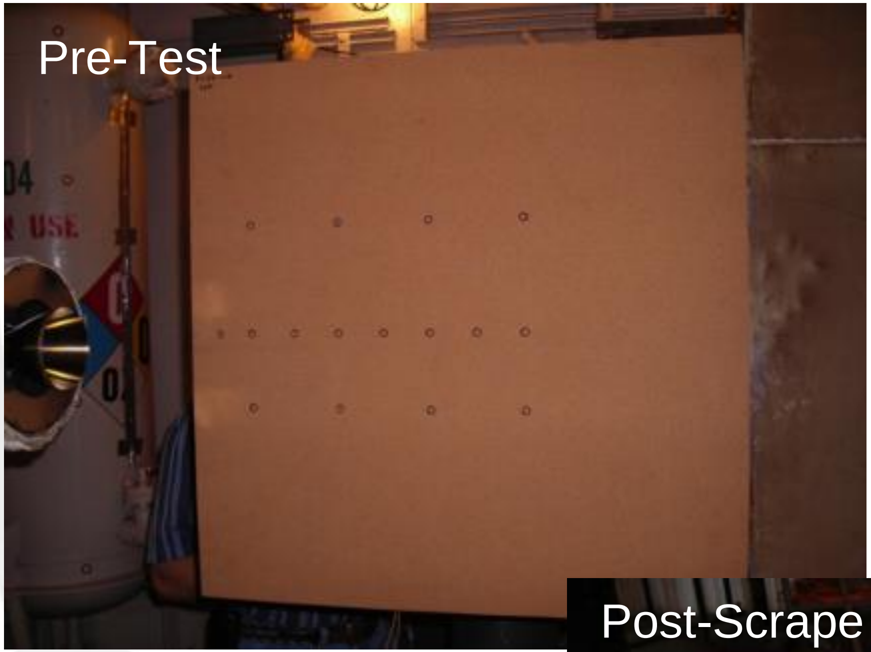


More Testing

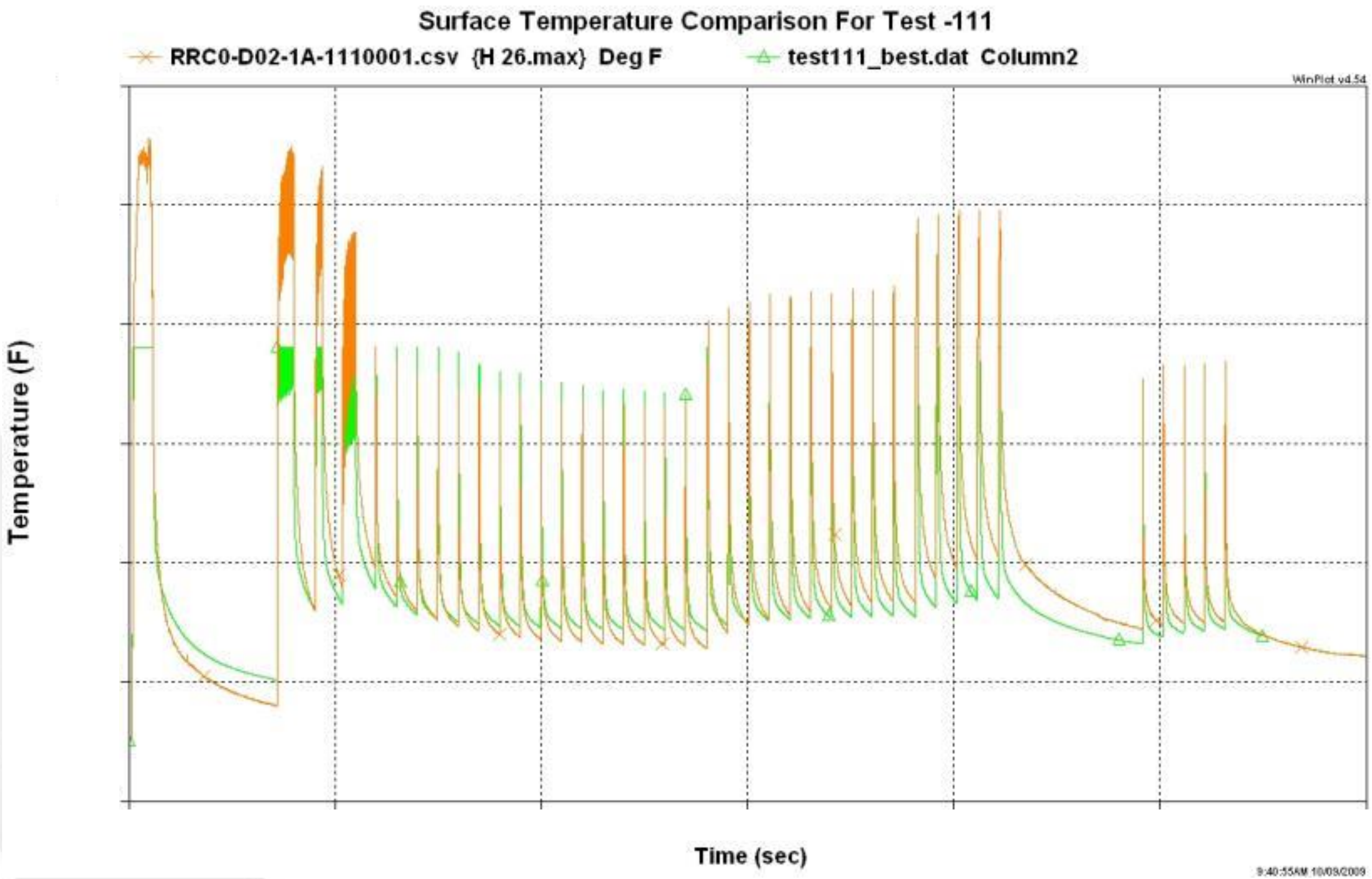
- Roll Control thruster testing at Aerojet test facility in Sacramento, California
  - Used a MR-80C, 625 lbf thrust monopropellant Hydrazine thruster
  - Generated 0 – 50 BTU/ft2 sec
  - Piggyback test
  - Not able to maintain constant heat rate.
    - Unable to plot recession rate versus heat rate.



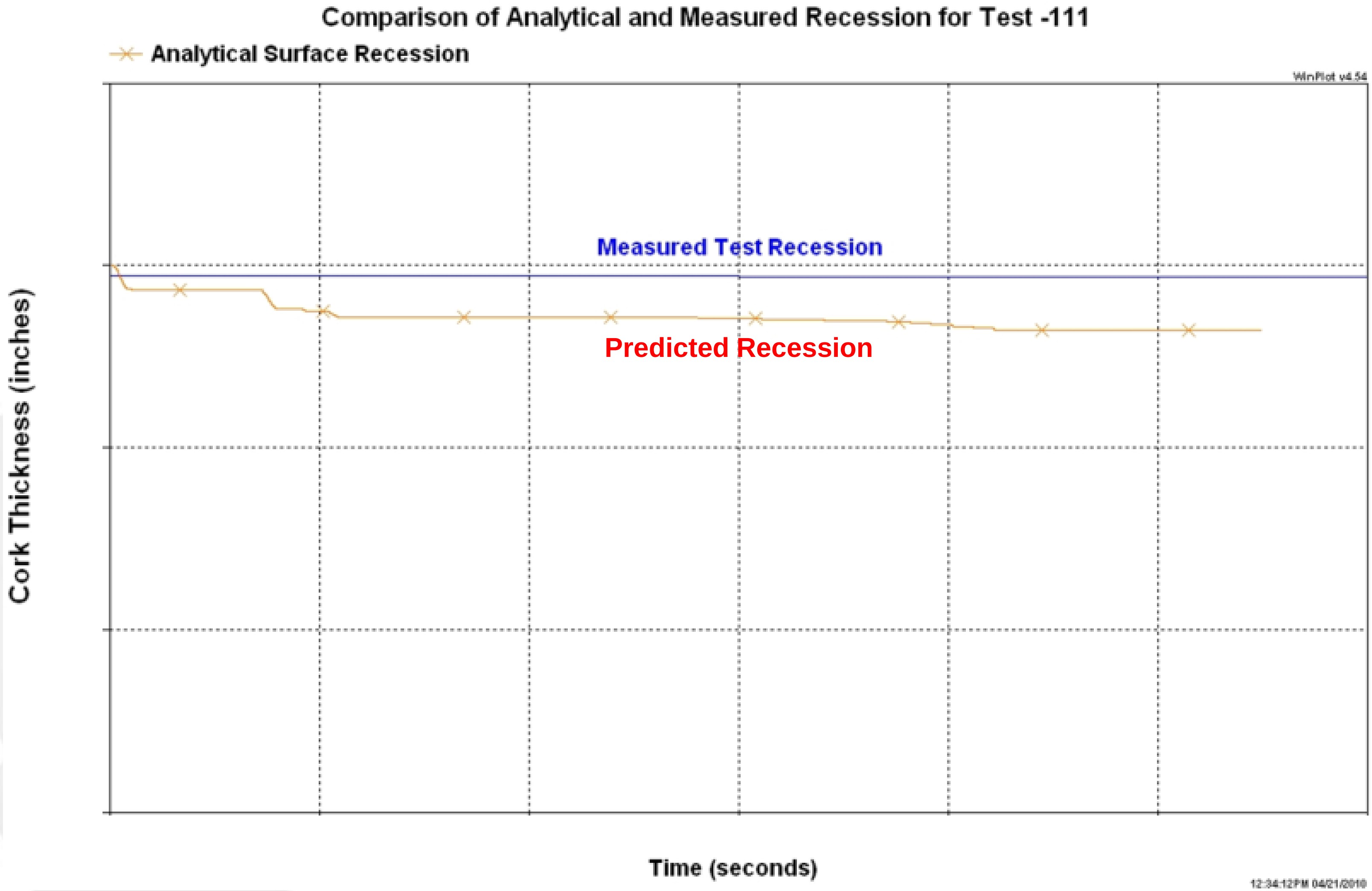
More Testing



More Testing

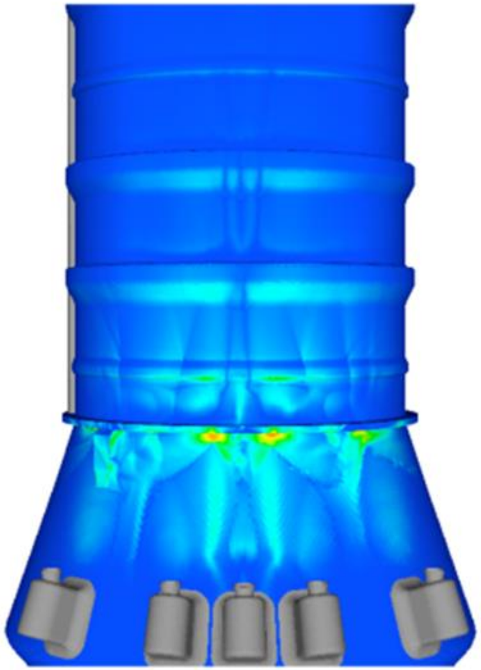


More Testing



Ares BDM Testing

- In the Ares design, the Booster Separation Motors (BSM) were turned and pointed upward, and renamed Booster Deceleration Motors (BDM)
  - In this configuration, the plume would impinge on several TPS materials
  - This created a new, untested, extreme environment.
    - High temperature, short duration, particulate.
  - More Testing!

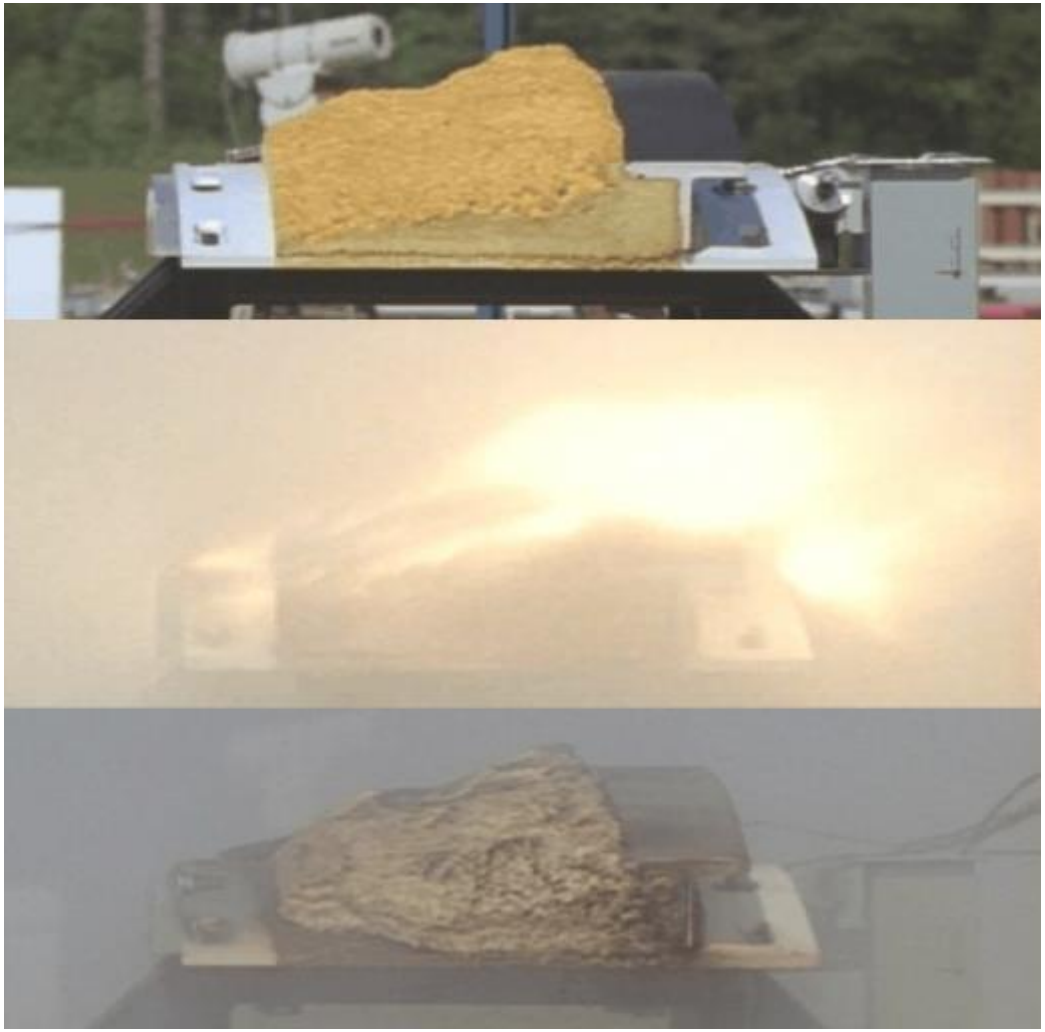


Ares BDM Testing

- The first test was performed at MSFC’s East Test Area

Ares BDM Testing

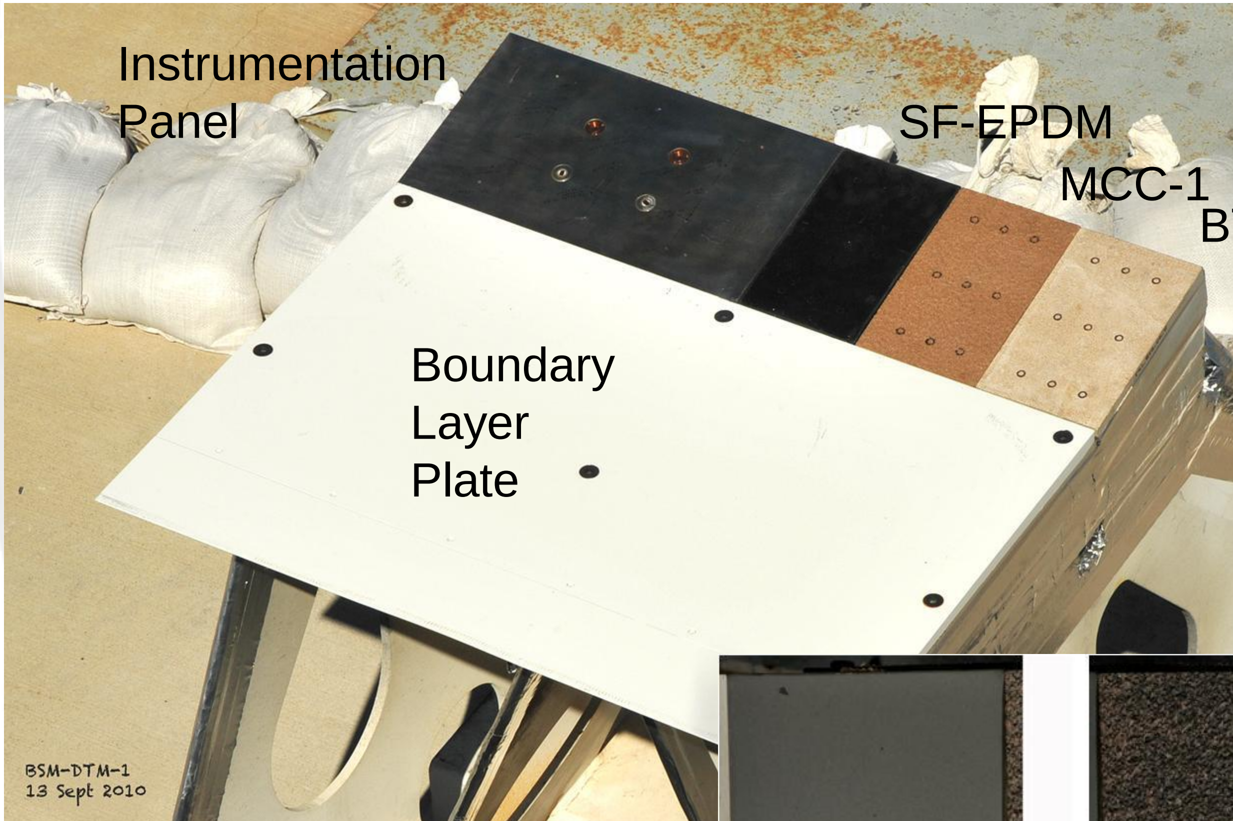
- The test was instrumented, but the main objective was to see if the foam would survive.
- As you can see in the second picture, the plume wrapped around the backside and burned most of our instrumentation leads.
- The foam did survive.
- A lot of times, the most important thing you learn in a test is what NOT to do next time!



Ares BDM Testing

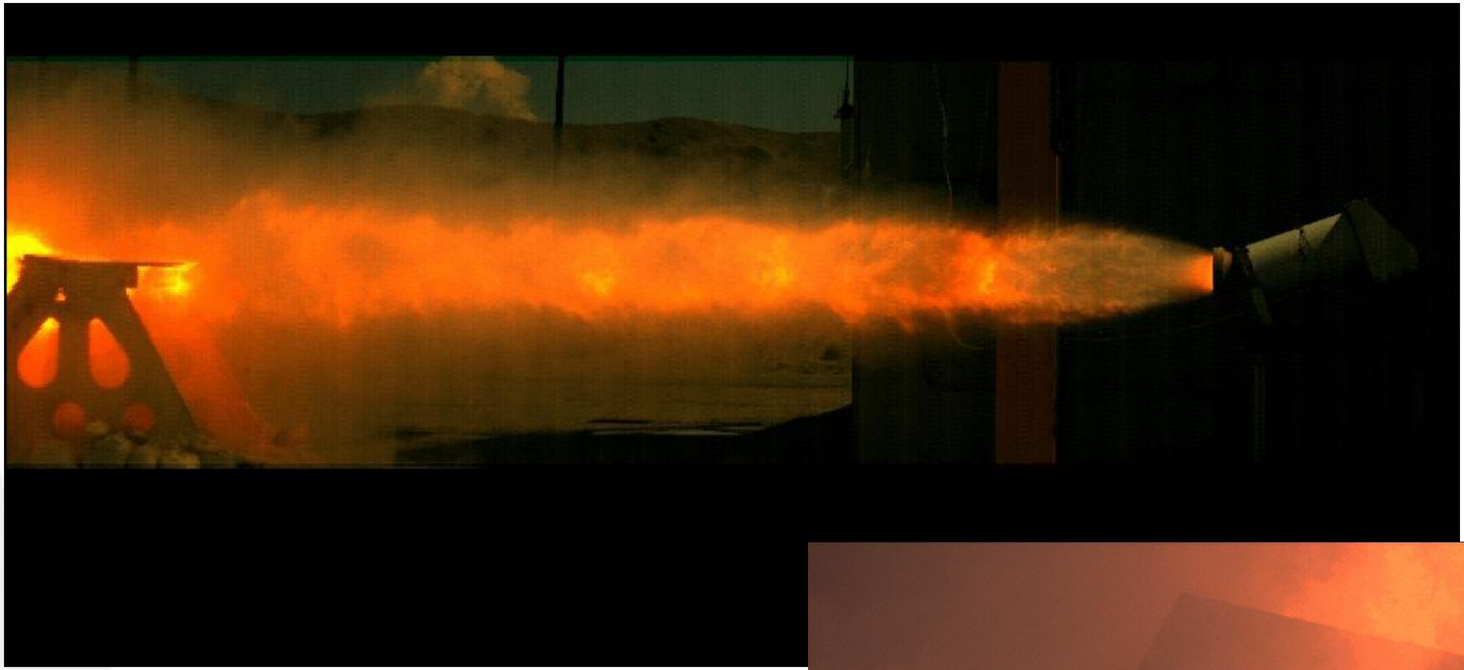
- The next tests were at ATK in Utah.
  - You can see the improvements from the previous test

Ares BDM Testing



Post-test Photographs

Ares BDM Testing



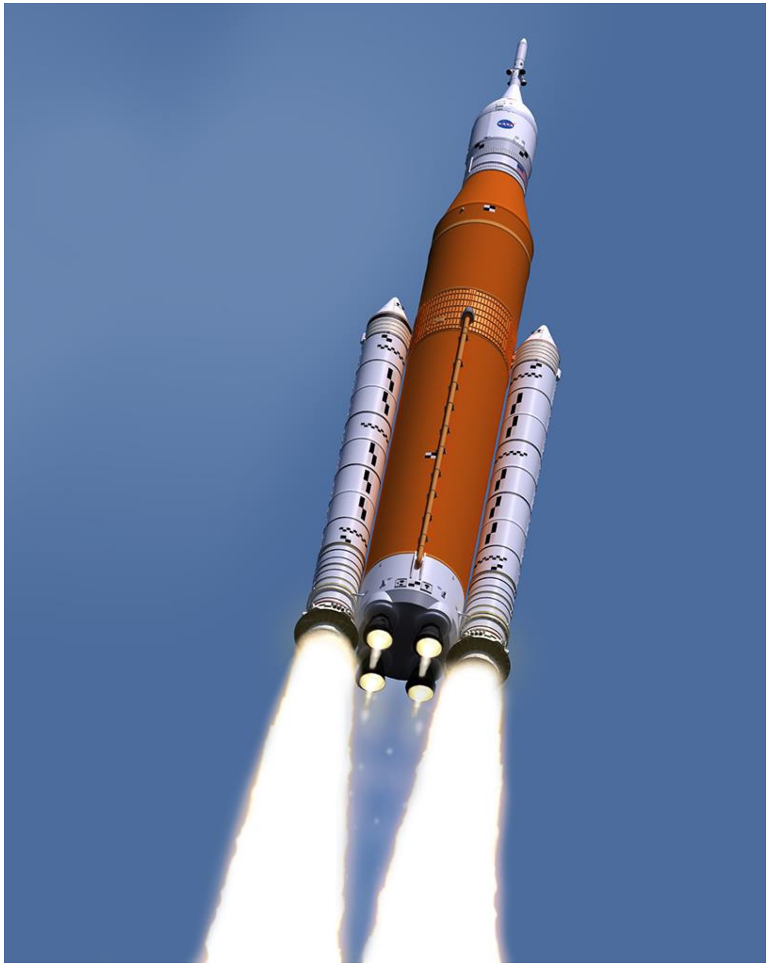
Motor fires for 0.8 – 1.0 seconds

Ares BDM Testing

Ares 1-X post-flight showing the effects of the BDM plume on foam used for water impact mitigation

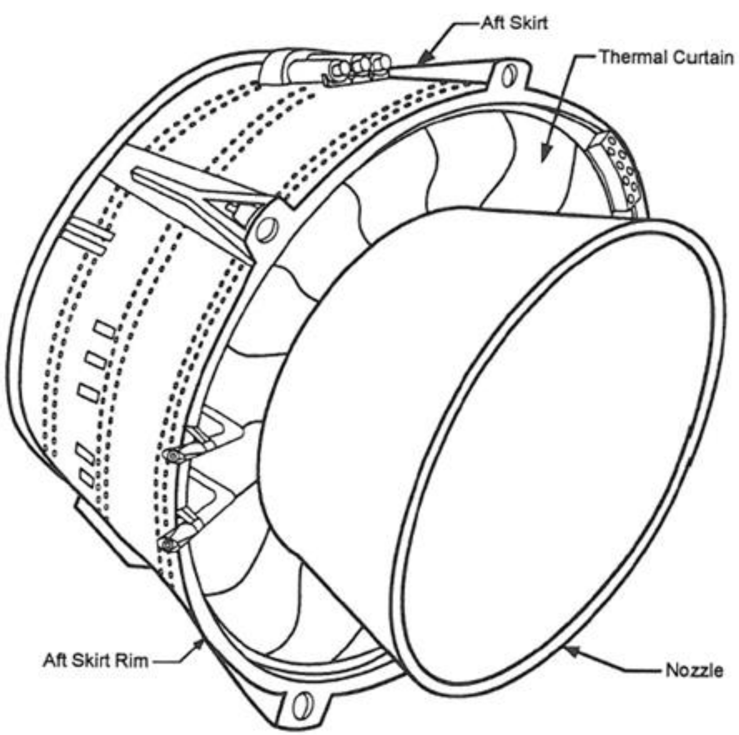
Differences between SLS and Shuttle

Thermal Curtain pre-ignition environments for SLS increased over heritage Shuttle



Thermal Curtain

- Viton/nylon layer in necessary for structural integrity during ignition overpressure
- Pre-launch SLS radiation environments increased
- SLS ascent environments were enveloped by Shuttle heritage
- Need design to protect 7 second Main Engine firing



Thermal Curtain

- The pre-ignition environment is purely a radiant environment.
- Tested at MSFC's Test Stand 300's radiant lamp bank.
- Viton/Nylon sample tested at a heat rate lower than design.
- Results showed the necessity of a design change.

Pre-test

End of Warm up

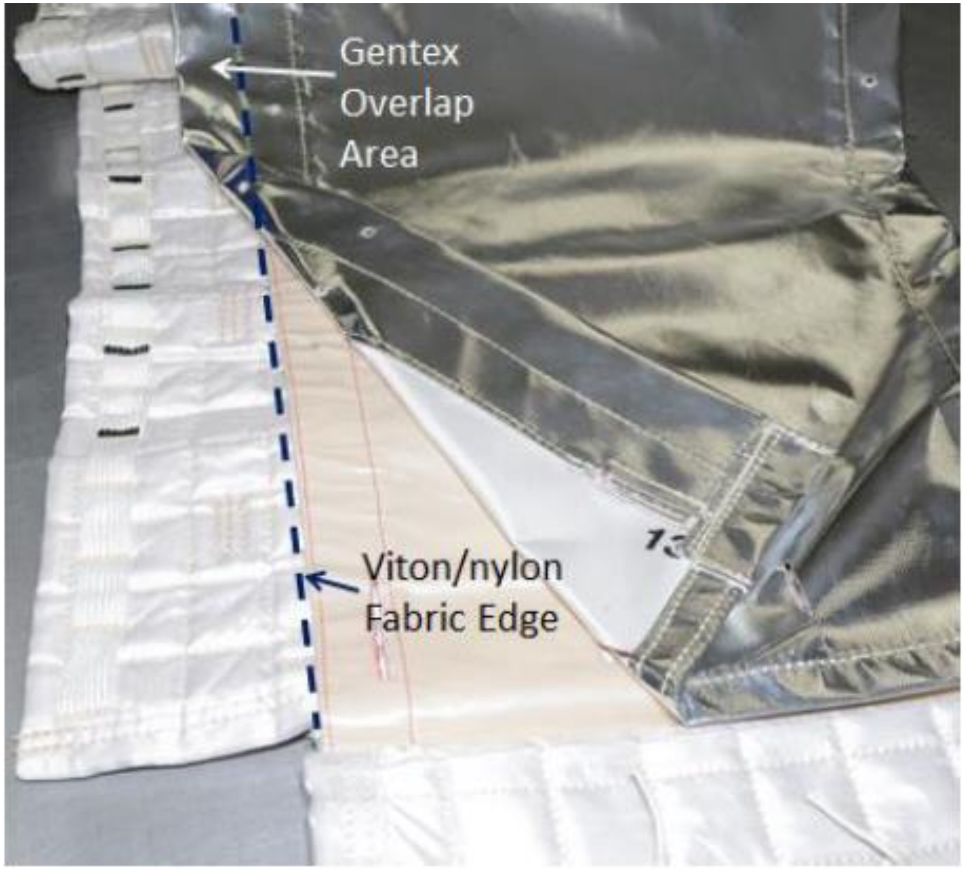
Thermocouple Loss / Flash Point

Simulated t-0

Post-test

Thermal Curtain

- Layer of highly reflective Gentex material added to Thermal Curtain layers.
- Since ascent environments are less than heritage Shuttle, Gentex only has to survive through the 7 second pre-ignition stage.



Thermal Curtain

- The Gentex layer is only required to survive one exposure.
- Since it performed so well, it was tested two more times to simulate potential launch scrubs after Main Engine start.

After first test

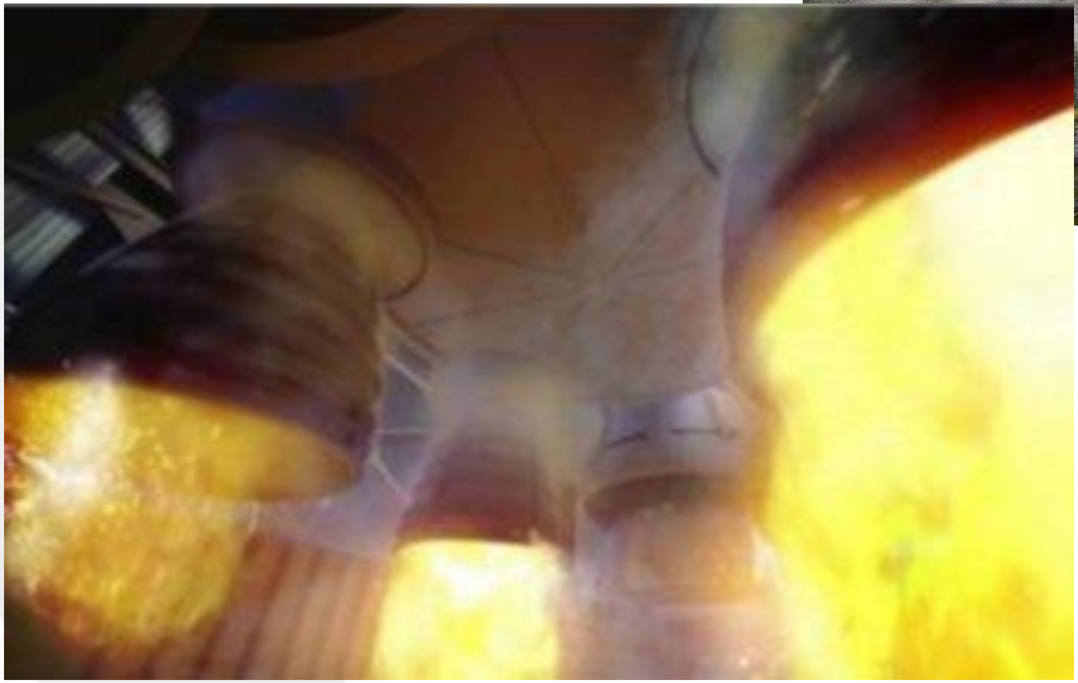
After second test

After third test

Core Stage Green Run

Core Stage plans a 500 second Green Run on an actual flight Core Stage to verify the Main Propulsion System.

Testing will be at the Stennis Space Center



Base Heat Shield is protected by P50 cork and is sized for flight.

Core Stage Green Run

- Base Heat Shield is protected by P50 cork and is sized for flight.
- Need additional TPS to protect for 500 second Green Run.
- However, we know our sizing methodology is conservative – there won't be as much ablation as we predict.
- So, there will be a lot of added cork still left on the flight vehicle.
    - More weight to carry – Core Stage is a 1:1 ratio
- Removing additional cork is time consuming and labor intensive
    - Produces dust that can damage surrounding hardware
    - May have to reapply Hypalon topcoat with an unqualified method

- Additional P50 is not a reasonable solution.
- Cannot attach any design solutions to test stand.
- Flight P50 cork cannot exceed 300 degrees F to maintain virgin properties
- Mitigating solution cannot cause slip in schedule to install, or remove.

Core Stage Green Run

- Proposed solution was to add reflective film to reflect radiant energy and add a layer of cryoinsulation foam to limit conduction.

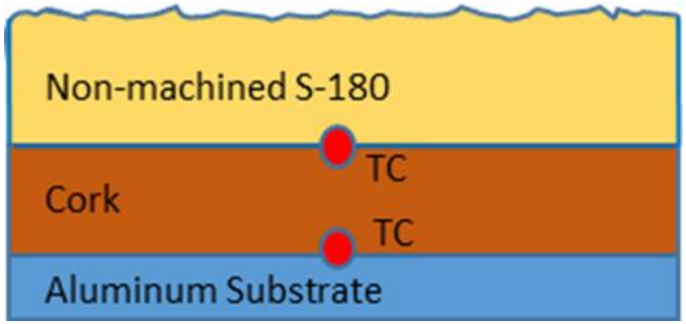
- Proof of concept testing at RHGF1

- Use radiant lamp and allow test area supply air to flow over panel to simulate cooling effect of ingested air.

- EV33, MSFC’s Aerosciences Branch provided both the flow rate for ingested air from a CFD model, and a Green Run radiant environment.

Core Stage Green Run

- First test was to verify the need for reflective film.

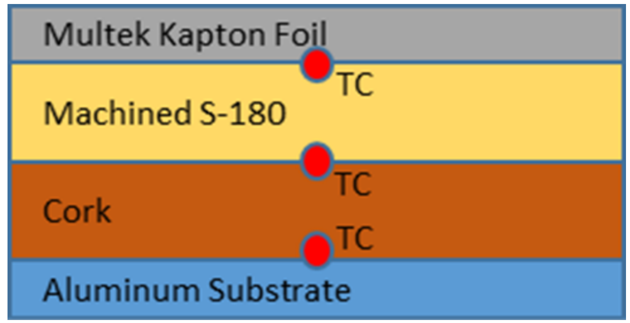


Pre-Test

Post-Test

Core Stage Green Run

- Next test was to verify the advantage of reflective film.



Pre-Test

Post-Test

Core Stage Green Run

- Results of the test were so successful that future testing will remove the S-180 and test the foil directly over the flight cork.

- Thermocouples will monitor surface temperature of cork.

- If this design is selected, it’s possible that the foil may be left on for flight.
  - Not as a thermal design requirement, but to reduce processing time.

Cryoinsulation

- Part II – Cryoinsulation – Analysis and Testing